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VARIETAL SUSCEPTIBILITY OF TOBACCO TO BROWN ROOT ROT IN CANADA[1]

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INTRODUCTION

As far as can be ascertained from a survey of the literature up to the present time, no concerted attempt appears to have been made to establish the existence or non-existence of varietal differences in susceptibility of tobacco to brown root rot. In the earliest report of brown root rot Johnson (1) states incidentally that "there seems to be no difference in varietal resistance to brown root rot." In a later publication Johnson, Slagg and Murwin (2) in Wisconsin point out "that no appreciable variation in resistance to brown root rot occurs in varieties of tobacco *Nicotiana tabacum*." More recently, Valleau and Johnson (3, 4) observed that "certain varieties show slightly greater resistance, as indicated by less wilting than others . . . . . at present the development of resistant strains does not seem to offer promise as a means of control."

Field investigations were begun in 1935 on a disease serious in southwestern Ontario and symptomatologically similar to the brown root rot prevalent in certain tobacco-growing areas of the United States. During 1936 in a plot designed originally to compare the morphological characters of 16 flue-cured varieties it was observed, incidentally, soon after the plants were transplanted that brown root rot was present throughout the plot and that consistent differences in varietal reaction to the disease were manifesting themselves. In consequence, a concerted effort was made to follow and compare the development of the disease in this plot, and in the following year experiments were designed to test the varietal susceptibility of both flue-cured and burley varieties. The results obtained to date are reported in this preliminary paper.

METHODS AND MATERIALS

Early in the investigation of brown root rot it was realized that the difficulty in obtaining satisfactory results from field experiments was simply that of inducing the disease at will. Soon, however, it was found

[1] Contribution No. 543 from the Division of Botany, Science Service, in co-operation with the Tobacco Division, Experimental Farms Service, Department of Agriculture, Ottawa, Canada. This contribution forms a part of a co-operative investigation on brown root rot of tobacco between the Dominion Laboratory of Plant Pathology, St. Chatarines, Ontario, and the Dominion Experimental Station, Harrow, Ontario.

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that on selected areas of the lighter tobacco soils at the Harrow Experimental Station brown root rot could, with reasonable certainty, be expected to develop in the tobacco crop, provided one or more satisfactory crops of corn preceded the tobacco. It was on such plots of ground that the relative resistance of flue-cured varieties was compared in 1936, and of both flue-cured and burley varieties in 1937. For these experiments, all varieties were planted on the same day and care was taken to subject all varieties and plants to similar conditions from the date on which seed was sown until they were transplanted to the field. Notes as well as photographs were taken of the different plots at intervals throughout the growing season. Frequent root examinations were also made to determine the relative severity of the disease on different varieties and also to find out whether or not affected plants were also suffering from black root rot or other root troubles. In so far as possible plot values were estimated and assigned throughout the season and yields were taken when the crop matured. It was considered unnecessary to include all such information in the present paper, and except for the experiment involving burley varieties in 1937 only the relative resistance of the different varieties estimated from the above information has been enumerated. Additional information was also obtained by careful observations of the occurrence of brown root rot, not only in all tobacco plots on the Station but also in all fields where the disease was encountered during an annual tobacco disease survey.

RESULTS

Flue-cured Varieties, 1936

In 1936, eight varieties of flue-cured tobacco were grown in randomized ($\frac{1}{32}$ acre) plots on 4 ranges, replicated 4 times, and 8 others in single 2-row plots. Fertilizer and cultural treatments were identical on all plots and, as mentioned previously, corn had preceded tobacco in the rotation. Definite differences in the size of above-ground parts of the different varieties were apparent 3 weeks after transplanting. Examination of the root systems of plants of different varieties showed that the amount of discoloration and rotting of the root systems was usually directly proportional to the degree of stunting of the above-ground parts.

A list of the varieties with their plot values, estimated yields per acre, grade indexes and reaction to brown root rot has been summarized in Table 1. As will be observed from an examination of this table, wide differences in results were obtained for different varieties (Plate I). Throughout the list, correlation between plot values, yields, and reactions will be observed. The marked degree of resistance of the varieties Bonanza, White Mammoth, Duquesne, and White Stem Orinoco was both outstanding and consistent throughout practically all ranges and replications. The same was true for certain of the varieties listed as susceptible, particularly Yellow Mammoth and White Stem Willow Leaf. Certain other varieties, however, were not entirely consistent in their reaction, parts of rows being severely stunted while other parts appeared to make normal growth. In such cases, however, the variety was regarded as susceptible, its behaviour explainable on the premises that the disease was not uniformly present throughout the soil of the entire area. Mention should also be made of the apparent measure of correlation between grade index and

reaction. Though this correlation was not marked, nevertheless, those varieties which exhibited greatest resistance to brown root rot also possessed highest grade indexes.

TABLE 1.—SUMMARY OF RESULTS OF AN EXPERIMENT IN VARIETAL SUSCEPTIBILITY OF FLUE-CURED TOBACCO VARIETIES TO BROWN ROOT-ROT IN 1936

Variety	Plot value July 25	Yield per acre in lbs.†	Grade index	Reaction
			cts.	
Adcock	40.0	88	27.2	Highly susceptible
Bonanza	73.5	447	30.1	Resistant
Cash	40.0	103	21.7	Susceptible
Duquesne	87.5	427	26.6	Resistant
Gold Dollar (strain 70B)	30.0	0	0.0	Highly susceptible
Gold Dollar (strain 70A)	70.5	422	23.6	Resistant
Gold Leaf	40.0	223	17.9	Susceptible
Harrison's Special*	65.0	388	25.9	Resistant
Jamaica Wrapper	40.0	94	26.4	Highly susceptible
Lizzard Tail	40.0	210	22.2	Susceptible
Silk Leaf	50.0	119	17.2	Susceptible
White Mammoth	77.5	420	25.7	Resistant
White Stem Willow Leaf	28.5	55	2 .7	Highly susceptible
White Stem Orinoco	70.0	449	22.9	Resistant
Warne	60.0	179	21.2	Susceptible
Yellow Mammoth	28.5	56	17.9	Highly susceptible
Yellow Bud Pryor	45.0	71	21.7	Highly susceptible

* The identity of this strain of Harrison's Special has not yet been definitely established.
† From two primings; then destroyed by hail.

Flue-cured Varieties, 1937

The experiment designed for the purpose of testing the resistance of flue-cured varieties in 1937 proved for the most part unsatisfactory due principally to the mild form of the disease on the ground selected. However, from experimental plots designed for other purposes but planted with flue-cured varieties and having a crop history appropriate for the development of brown root rot, certain interesting information was obtained. Where the disease was more or less uniformly distributed in these plots and where different varieties were grown adjacently, Yellow Mammoth and White Stem Willow Leaf were consistently more seriously affected by brown root rot than White Mammoth, Bonanza, Duquesne, and White Stem Orinoco.

Burley Varieties, 1936

In 1936 no experiment was specifically designed to determine the relative resistance of burley varieties. However, careful examinations of plots of adjacent but different varieties on soil where brown root rot developed in severe form yielded the evidence that the varieties Harrow Velvet and Halley's Special were consistently more severely affected than Judy's Pride and Kelley.

Burley Varieties, 1937

In 1937 two plots of ground, which had during 1936 produced excellent crops of corn and which were regarded as being especially favourable for the development of brown root rot, were selected for testing the relative

resistance of the common burley varieties. On each plot, duplicate rows of seven varieties were grown with the exception of the variety Kelley (306), which was replicated twice on each plot. Throughout one of these plots brown root rot appeared to be more or less uniformly distributed in severe form, and consistent differences in the relative resistance of the varieties became evident. A summary of the results of this experiment on the severely-affected plot appears in Table 2 (see Plate II). Results obtained from the second plot are not given because on it the disease did not occur in epidemic form. To supplement the tabulated information, a graphic representation of all varieties and plants in this plot, their relative positions and the degree of infection is presented in Figure 1. The severity of

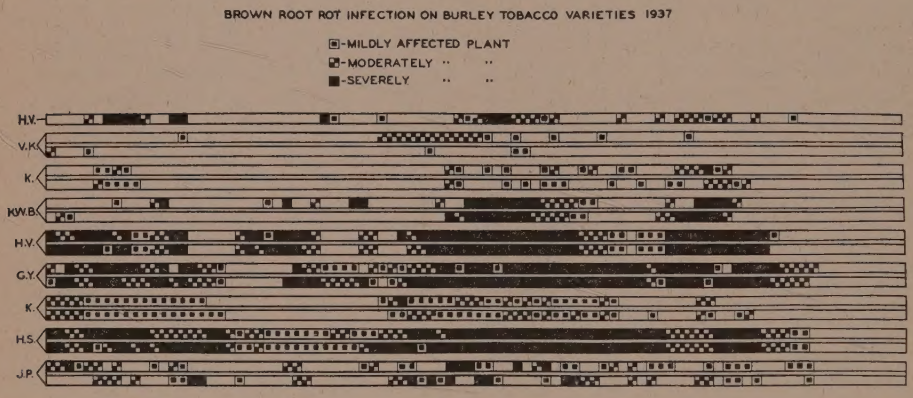

FIGURE 1. H.V.—Harrow Velvet (2 rows and 1 guard row). V.K.—Vimont Kelley (2 rows). K.—Kelley (4 rows). K.W.B.—Kentucky White Burley (2 rows). G.Y.—Gays Yellow (2 rows). H.S.—Halley's Special (2 rows). J.P.—Judy's Pride (2 rows).

infection of individual plants was arbitrarily estimated from the size of the above-ground parts. After considerable investigation of this point on the plot in question it was determined that for the most part the size of the plant above-ground varied directly with the infection of its root system.

TABLE 2.—A SUMMARY OF THE RESULTS OF AN EXPERIMENT TO DETERMINE THE REACTION OF BURLEY TOBACCO VARIETIES TO BROWN ROOT ROT IN 1937

Variety	Relative infection and no. of plants				Total no. infected plants	Yield per acre in lbs.	Reaction
	Healthy	Mild	Moderate	Severe			
Vimont Kelley	162	10	12	0	22	948	Resistant
Kelley 306 (average 4 rows)	119	43	21	1	65	656	Resistant
Kentucky White Burley	130	7	18	29	54	689	Moderately resistant
Judy's Pride	111	32	26	15	73	527	Moderately resistant
Harrow Velvet	56	17	26	85	128	441	Highly susceptible
Gays Yellow	41	16	38	89	143	356	Highly susceptible
Halley's Special	24	29	41	90	159	300	Highly susceptible

An examination of Table 2 reveals wide variations in the yield of different varieties. It will be observed that there is a definite and consistent correlation between the number of healthy plants in the different varieties and their respective yields, the number decreasing with the yield. A similar correlation is apparent between the total number of infected plants in each variety and the yield, the number in this case increasing as the yield decreases. It should be mentioned that both the yield figures and grade index for the variety Judy's Pride were somewhat lower than they should normally have been, due to barn burn during curing operations.

Another important fact in connection with the figures presented in Table 1 is the relative severity of the disease in the different varieties. In varieties such as Kelley, Vimont Kelley, and Judy's Pride which appear to offer a measure of resistance to brown root rot the values in the "moderate" and "severe" columns of Table 2 decline sharply. This is in direct contrast with the trend in the highly susceptible varieties such as Harrow Velvet, Gays Yellow, and Halley's Special. The reaction of Kentucky White Burley, mentioned again below in connection with Figure 1 was difficult to determine, as will be observed by an examination of the figures, but this variety appeared to offer some measure of resistance.

The facts presented in Table 2 strongly indicate that brown root rot, rather than other factors such as inherent varietal differences, was primarily responsible for the differences demonstrated by this experiment. Aside from these facts, however, it is quite possible that the reaction of these varieties to brown root rot in the future may not always be precisely as they are listed in Table 2.

Before continuing with a discussion of Figure 1 it should be mentioned that confirmation of the relative resistance of the varieties Kelley and Judy's Pride as contrasted with the extreme susceptibility of Harrow Velvet and Halley's Special was obtained in 1937 on a "brown root rot" plot widely separated from the one just discussed, the resistance of these varieties being tested in single adjacent rows (Plate II, lower).

An examination of Figure 1 elucidates certain facts not presented in the table. Before discussing these it should be pointed out that one outside row of Harrow Velvet plants, adjacent to Vimont Kelley, has been represented in the chart. Though this row of plants was used in the experiment only as a guard row and, therefore, not utilized in the results, it was, nevertheless, included in the chart to show the presence of the disease in the soil to the outside of the plot, the infection of the susceptible variety Harrow Velvet contrasting rather sharply with that of adjacent varieties. Though the disease was apparently more concentrated in severe form in one portion of the plot and entirely lacking in one end, nevertheless, consistent differences in the incidence of infection on different varieties is apparent. Susceptibility of the variety Harrow Velvet is apparent not only by the large number of severely affected plants in the two rows at the centre of the plot, but also by the number of affected plants in the guard row. Vimont Kelley appeared to exhibit a measure of resistance though this is not convincingly demonstrated because of its location in the more mildly diseased portion of the plot. Virtually the same may be said for Kentucky White Burley though the chart indicates a lesser degree of resistance for this variety. On the other hand resistance on the part of

the variety Kelley appears to be much more convincingly demonstrated because in none of the four rows of this variety did the disease manifest itself in severe form. The mild infection of the plants of this variety contrasts sharply with the severe infection in the highly susceptible varieties Gays Yellow and Halley's Special on either side. The variety Judy's Pride also appears to offer a distinct measure of resistance when its reaction is compared with that of the adjacent variety, Halley's Special, in the more severely diseased portion of the plot.

DISCUSSION

From the practical standpoint the demonstration of differences in varietal susceptibility of tobacco to brown root rot is of considerable value, offering, as it does, interesting possibilities for control. The extreme susceptibility of the flue-cured varieties Yellow Mammoth and White Stem Willow Leaf has contrasted strikingly with the apparent resistance of the varieties White Mammoth, Bonanza, Duquesne, and White Stem Orinoco. In the burley varieties, the extreme susceptibility of Harrow Velvet, Halley's Special, and Gays Yellow as compared with the measure of resistance offered by Kelley and Judy's Pride has also been outstanding. However, although the differences in varietal susceptibility just mentioned, as well as certain others pointed out previously, have been both marked and in general quite consistent during the past two years, nevertheless, there is no positive assurance that they will remain so.

In field experiments involving varietal susceptibility there is always the possibility of interpreting escape as resistance. This danger is reduced to a minimum, however, when results are obtained from replications and from widely-separated plots, as was usually the case in the present experiments. In the present instance there is also the possibility that the root disease under investigation in Canada may be different from the disease known as brown root rot in the United States. However, both symptoms and the circumstances under which this tobacco disease develops strongly indicate it to be similar to the brown root rot reported from and still existent in the Connecticut Valley.

It should be emphasized in the present investigation that resistance to brown root rot of the flue-cured and burley varieties referred to above is in no instance regarded as absolute but rather as relative. In the field, for instance, cases have been observed of Bonanza (flue-cured) and Judy's Pride (burley) varieties affected to some extent with brown root-rot. In the majority of such cases, however, it was impossible to compare their reaction with that of other varieties since only one variety was planted in a single "root rot" field.

Another interesting but puzzling fact disclosed by the investigation to date has been the observation that the burley variety Harrow Velvet which is outstandingly resistant to black root rot, appears to be one of the most susceptible varieties to brown root rot. On the other hand, the varieties Judy's Pride and Kelley, which are extremely susceptible to black root rot, appear to be markedly resistant to brown root rot. In conclusion, it may be pointed out that while the results of this investigation to date must be regarded as preliminary, they have demonstrated a promising possible means of control for brown root rot in Canada and amply warrant further investigation along these lines.

Varietal resistance of flue-cured varieties of tobacco to brown root rot. *Upper:* First range (lower) to right—(short plants) Yellow Mammoth; to left—(taller plants) White Mammoth. Note plot differences on all ranges. *Middle:* (Five rows for variety) First range—(right) Bonanza; (centre) Yellow Mammoth; (left) Duquesne. Second range—(centre) Duquesne. *Lower:* (right) Yellow Mammoth; (left) Bonanza (after first priming).

Varietal resistance of burley varieties of tobacco to brown root rot. *Upper:* (Duplicate rows) A—Judy's Pride, B—Halley's Special, C—Kelley, and D—Gay's Yellow. *Middle:* (Duplicate rows) A—Judy's Pride, B—Halley's Special, C—Kelley, D—Gay's Yellow, and E—Harrow Velvet. *Lower:* (Single rows) A—Kelley, B—Halley's Special, C—Harrow Velvet, D—Judy's Pride.

SUMMARY

(1) Differences in varietal susceptibility of flue-cured and burley tobacco varieties to brown root rot in Canada are reported for the first time.

(2) Two-years' experiments have indicated extreme susceptibility to brown root rot in the flue-cured varieties Yellow Mammoth, White Stem Willow Leaf, and considerable resistance in the varieties White Mammoth, Bonanza, White Stem Orinoco and Duquesne. Of the burley varieties, Harrow Velvet, Gays Yellow and Halley's Special proved highly susceptible while Judy's Pride and Kelley offered distinct resistance.

(3) Certain burley varieties which are most susceptible to black root rot appear to be most resistant to brown root rot in Canada, and *vice versa*.

ACKNOWLEDGMENT

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A FIELD STUDY OF THE FLIGHT, OVIPOSITION AND ESTABLISHMENT PERIODS IN THE LIFE CYCLE OF THE EUROPEAN CORN BORER, *PYRAUSTA NUBILALIS* HBN., AND THE PHYSICAL FACTORS AFFECTING THEM

IV. THE OVIPOSITION AND ESTABLISHMENT PERIODS. ANNUAL CYCLE OF OVIPOSITION. DAILY CYCLE OF OVIPOSITION. FLIGHT AND OVIPOSITION. EGG MORTALITY AND SURVIVAL. LARVAL MORTALITY AND SURVIVAL.

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THE OVIPOSITION AND ESTABLISHMENT PERIODS

Review of the General Literature

The literature dealing with oviposition and establishment is scattered in general references to the life history and control of the borer. The largest portion of the literature deals with variations in oviposition and establishment in relation to corn types and varieties, or with corn planted at various dates. We are not concerned with these subjects in the present paper and will not review the literature referring to them.

Schmidt, in 1835, was the first to refer to the eggs and young larvae according to Jablonowski (11). Schmidt discovered that the eggs were laid on the leaves and stalks of millet in Hungary.

Taschenberg, in 1880, was apparently the first to describe eggs on corn; he found eggs on the sheaths of leaves. He knew also that the larvae, upon hatching, burrowed into the stalk.

Bako, of the Hungarian Entomological Station, published a general paper on the corn borer according to Jablonowski (11) in which he described the eggs as being laid upon corn leaves in little clusters containing a minimum of from 22 to 35 eggs.

Vinal (20) was the first American worker to describe the eggs. This author, in 1917, stated that they were laid on the corn stalks, an impression he no doubt obtained from the scanty European literature. Vinal and Caffrey (21) two years later, pointed out that the eggs were laid in masses of from 5 to 50 eggs upon the under surface of corn leaves.

OVIPOSITION

The Annual Cycle of Oviposition

Detailed records of egg laying by days and by individual corn plants have been secured for each year. In 1929, due to a misunderstanding, egg laying had commenced before our records were started and part of the data was missed. In 1930 and for a portion of 1931, in 1935, and in a portion of 1936, egg laying records were taken every other day instead of every day as in the other years.

[1] Entomologist in Charge.

The Seasonal Limits and Fluctuations in the Oviposition Period

The seasonal limits and seasonal fluctuations are shown in Figures 1 and 2 and in Table 1.

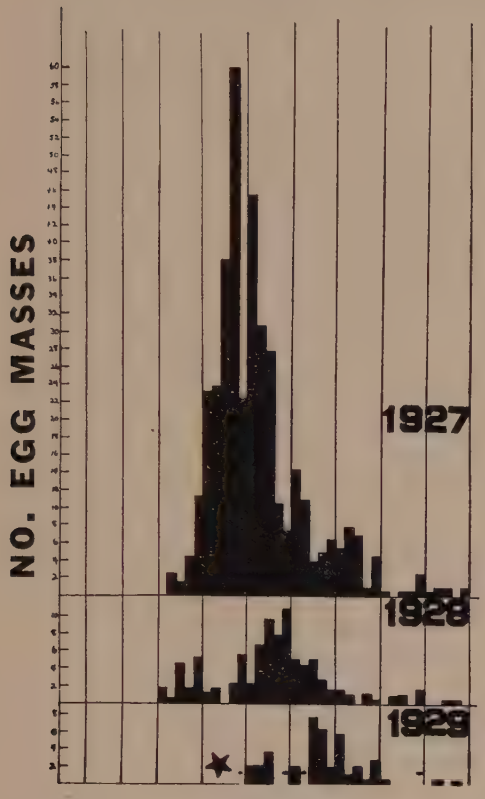

FIGURE 1. Number of egg masses laid daily on 100 corn plants, Chatham, Ontario, 1927–29. The dashes indicate nights upon which records were not secured; eggs laid on these nights are included with those of the next night. The star indicates that early records were not secured in this year.

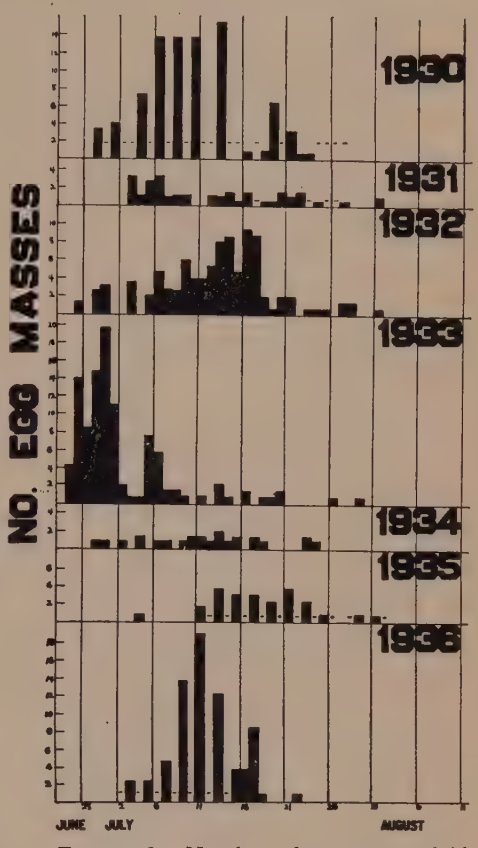

FIGURE 2. Number of egg masses laid daily on 100 corn plants, Chatham, Ontario, 1930–36. The dashes indicate nights upon which records were not secured; eggs laid on these nights are included with those of the next night.

TABLE 1.—THE SEASONAL LIMITS OF THE OVIPOSITION PERIOD, CHATHAM, ONTARIO, 1927–36

Year	Date of commencement of oviposition	Date of apparent peak of oviposition	Date of termination of oviposition
1927	July 7	July 14	August 9
1928	July 6	July 20	July 30
1929	July 4	—	August 8
1930	June 29	July 13	July 24
1931	July 3	July 6	July 31
1932	June 27	July 16	July 31
1933	June 26	June 30	July 20
1934	June 29	July 13	July 24
1935	July 4	July 13	July 31
1936	July 3	July 11	July 22
Average date	July 2	July 15	July 29

Crawford and Spencer (5) found eggs as early as June 21 in Elgin county, Ontario, in 1921, but egg laying did not become general until about July 1. Ficht (unpublished) found eggs at Wheatley, Ontario, on June 23, 1925 and at Chatham, Ontario, on July 5, 1926. Bottger and Kent (2) have studied the seasonal oviposition periods in southern Michigan. Their data are reproduced in Part II, Table 2, page 465. Egg laying in Ontario occurs a few days later than it does in southern Michigan.

TABLE 2.—RATE AT WHICH OVIPOSITION PEAK IS REACHED AFTER COMMENCEMENT OF FLIGHT, CHATHAM, ONTARIO, 1927–36

Year	No. of days to reach peak	Year	No. of days to reach peak
1927	7	1932	19
1928	14	1933	4
1929	9	1934	14
1930	14	1935	9
1931	3	1936	8
Average for all years			10

The Rate of Developing Oviposition Peak

There is a considerable variation in the rate at which the oviposition peak is reached from year to year. This is shown in Table 2.

A detailed knowledge of the character of the annual cycle of oviposition and its variations is important when considering experimental or practical control by ovicides or larvicides, as very often the time of application will govern the success or failure of the operation.

The Magnitude of Oviposition

Magnitude of oviposition can be measured in a number of ways. It can be measured according to the number of egg masses per 100 plants, or by the total number of eggs laid per 100 plants. Both of these measurements will be considered below.

The Seasonal Magnitude of Oviposition

The magnitude of oviposition, based upon the number of egg masses laid per 100 plants is shown in Figures 1 and 2. There is a considerable variation from season to season. The largest number of egg masses for any one season was laid in 1927, while the least number was laid in the years 1931, 1934 and 1935.

The Number of Eggs per Mass

The number of eggs found in each mass was counted during the 10 years' observations and Table 3 is a summary of these records.

The individual masses contained from 1 to 59 eggs.

The average number of eggs per mass in the years recorded is smaller than the average number of eggs per mass found by Ficht (unpublished) in 1925 and 1926. At Wheatley, in 1925, the average egg mass contained 20.4 eggs, while at Chatham, in 1926, the average mass contained 19.6 eggs. The records were obtained from 1412 and 1502 egg masses respectively. These years were not only favourable to egg production, but for some reason the moths laid more eggs per mass than is usual.

Caffrey (4) records that in New England during the years 1917 to 1921, and for two generations a year, the egg clusters have varied in size from 1 to 162 eggs, the average number being 14.6. In New York, with the univoltine borer, the average was 14.5 in 1923, and 16.7 in 1924, while in Ohio it was 14.0 in 1923 and 15.5 in 1924.

Bottger and Kent (2) state that in southern Michigan, during the years 1926 to 1930, the average number of eggs per mass has been 17.0 for each season.

At Chatham, there was considerable variation in the number of eggs per mass from year to year. Moths did not lay as many eggs per mass in 1931 as they did in 1927 or 1934.

TABLE 3.—THE AVERAGE NUMBER OF EGGS PER MASS, CHATHAM, ONTARIO, 1927–36

Year	Average number of eggs	Year	Average number of eggs
1927	18.4	1932	16.8
1928	15.1	1933	15.1
1929	14.6	1934	17.9
1930	16.6	1935	15.4
1931	12.7	1936	15.5
Average for all years			15.8

In most years the time of season in which an egg mass is laid does not affect the number of eggs it will contain. In some years, however, as in 1932 and in 1936, the size of the masses in the last half of the oviposition period was markedly smaller than that laid during the first half of the period. This may be seen from Table 4.

TABLE 4.—AVERAGE NUMBER OF EGGS PER MASS IN FIRST HALF AND LAST HALF OF OVIPOSITION SEASON, CHATHAM, ONTARIO

Year	First half of season	Last half of season
1927	18.7	20.5
1928	14.0	15.2
1930	15.7	14.2
1931	12.1	14.1
1932	19.2	16.1
1933	15.3	15.1
1934	17.4	18.6
1935	16.3	16.0
1936	20.9	12.9
Average	15.8	16.6

It would appear also that conditions in the first half of the season in 1931 and the last half of the season in 1936 were favourable to the production of smaller egg masses.

The seasonal magnitude of oviposition may also be shown by the total number of eggs laid per 100 plants. These data are given in Table 5.

By far the largest number of eggs per 100 plants were laid in 1927. The total number of this year, however, is far below those of 1925 and 1926, the years in which the borer was at its height of activity and damage. Ficht (unpublished) secured 28,870 eggs per 100 plants per season in 1925 at Wheatley, Ontario, and in 1926 he secured 29,452 eggs per 100 plants per season at Chatham, Ontario.

The Daily Magnitude of Oviposition

The number of egg masses per 100 plants laid each night for all season is plotted for each night in Figures 1 and 2. The number of egg masses per 100 plants per night has varied from none to 60.5. The number, as will be shown later, is a function of the number of moths in flight.

The Relationship Between Flight and Oviposition

The egg laying curve naturally follows that of the flight of moths. This may be seen from comparing Figures 1 and 2, Part II, with Figures 1 and 2 of Part IV. There are, however, some variations in the two curves and these will be discussed below.

The number of eggs per female per 100 plants per night and for each season has been calculated. This value for the various years under study is summarized in Table 6.

Table 5.—Total number of eggs laid per 100 plants for entire season, Chatham, Ontario, 1927–36

Year	Total number of eggs	Year	Total number of eggs
1927	7,117	1932	1,594
1928	1,561	1933	1,537
1929	794	1934	311
1930	1,416	1935	351
1931	337	1936	1,110
Average			1,612

The best years for egg laying were 1934, 1935 and 1936, while the worst years were 1927 and 1928. It is interesting to note that, in general, the last 3 years were probably the hottest and driest years experienced during the study while 1927 and 1928 were the coolest and with abundant moisture.

The variations in the number of eggs laid per female per 100 plants from night to night during the season is great. It has varied from 0 to 6.5 eggs. In some years the moths lay more eggs per female in the first half of the season and in some years the reverse is true. This is shown plainly in Table 7.

Table 6.—The number of eggs laid per female moth, per 100 plants during season, 1927–36

Year	Eggs per Female	Year	Eggs per Female
1927	4.9	1932	9.6
1928	2.5	1933	6.8
1929	7.6	1934	12.9
1930	9.0	1935	15.2
1931	5.1	1936	11·8
Average			8.5

The years 1934, 1935 and 1936 were not only the best years for egg laying, but the latter portion of these seasons was apparently more favourable for egg laying than was the first half. In 1931, the last half of the season was poorer for egg laying than was the first half.

The Effect of Temperature and Other Factors Upon Number of Eggs Laid per Female

The number of eggs laid per female per 100 plants on certain nights in the years 1928, 1931, 1934, 1935 and 1936, is plotted against the average temperature for the period of flight in Figure 3. Saturation deficiency and wind are also shown.

It is seen that in 1928 the number of eggs laid per female was lower than for any other year plotted. It was highest for 1936. This year had the highest temperatures of any year during the flight and oviposition period. There does not appear to be any correlation between temperature

and number of eggs laid per female per night. The same is true for humidity and wind. It would appear that the seasonal temperature acting over 24 hours per day regulated the number of eggs laid, and not the temperature prevailing at time the moths are in flight.

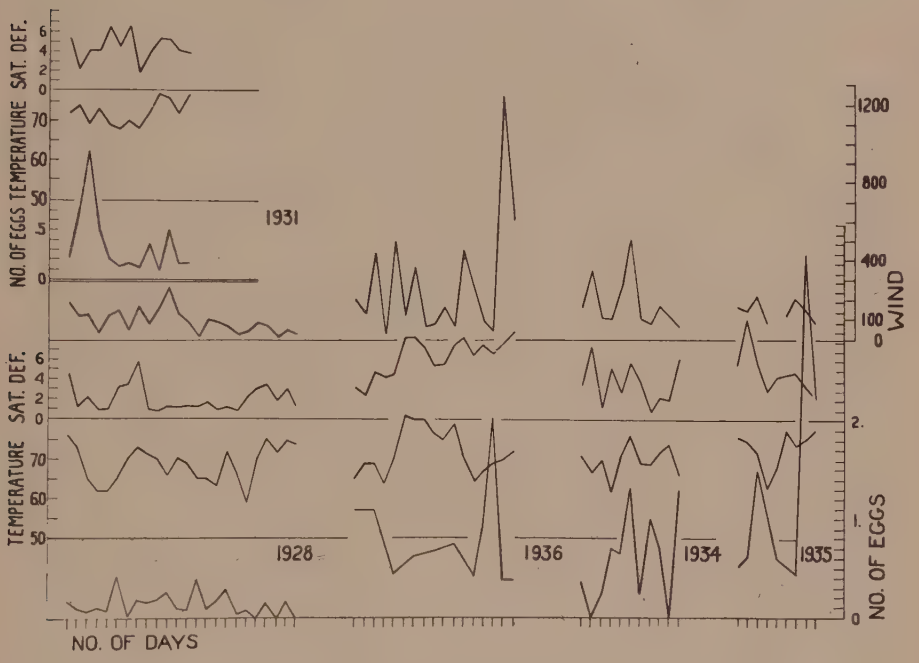

FIGURE 3. Chart showing relationship of certain physical factors to number of eggs laid per female per night.

The Increase in Number of Eggs Laid with Increase in Female Population

In general, when moths were secured in the flight plot, egg masses were secured in the establishment plot, and when moths were not secured in flight plot egg masses were not secured in the establishment plot. This association is quite striking and uniform from year to year. The apparent errors in sampling are, in most cases, very small and occur in the earlier years of work or during the early part of the season. Apparent errors are of two kinds: *(a)* where egg masses were secured, but no moths were observed in flight on that particular night; or *(b)* when moths were observed in flight, but no egg masses were found.

If the very minor errors of sampling of less than one egg mass per 100

TABLE 7.—EGGS PER FEMALE PER 100 PLANTS PER NIGHT IN FIRST AND LAST HALF OF OVIPOSITION SEASON, CHATHAM, ONTARIO, 1927–36

Year	First half of season	Second half of season
1927	.36	.36
1928	.28	.38
1930	1.14	1.65
1931	.45	.21
1932	.86	.83
1933	.60	.41
1934	.64	.80
1935	.88	1.73
1936	.78	.82

plants per night, or less than 2 moths per night be disregarded, the apparent inaccuracies are very small in number.

Eggs, but no moths, were secured on the following nights: July 19, 1927; July 8 and July 10, 1928; July 18, 1929; July 22, 1930; July 3, 1931; and July 2, 1933. July 19, 1927, July 18, 1929 and July 2, 1933, were cold nights and below the temperature for flight to take place; moths did, however, fly and laid eggs unobserved by us.

On July 8 and July 10, 1928, only two observation periods were patrolled and the operator was in error in leaving at such an early period as moths must have flown later in the night. July 22, 1930, was a night near the end of the flight period and only two observational periods were patrolled. Moths flew later in the evening. At the same hours on ensuing nights, moths were not secured except on July 24 and so the operator was correct in his surmise that flight was terminating.

July 3, 1931, is the only night in which meteorological factors for flight and observation patrols were normal in every way. Four observations were taken and no moths secured; flight did take place, however, in plot B. On this night, therefore, moths were present in the establishment plot and in plot B, but not present in plot A.

The apparent error of having moths in the plot but no egg masses is not serious, as moths may not have laid eggs although they were present in the field. Moths were observed in the field, but no eggs were secured on July 22 and July 28, 1932; July 10, 12 and 15, 1933; July 3 and July 19, 1934. July 28, 1932, and July 10, 12 and 15, 1933, were cold nights and the temperature was 58° F. or 59° F. at 1:30 Sunset time; flight would terminate very quickly as the temperature dropped further below the minimum required for moth activity during the course of the night. These records suggest that low temperature may affect egg laying more quickly than flight.

No peculiarity of the night which would cause moths not to lay eggs can be seen from the records of July 22, 1932, July 3 and July 19, 1934, although during flight on July 19, 1934, avery heavy rain occurred. It rained at the rate of 0.04 inches per hour.

TABLE 8.—SHOWING RELATION BETWEEN EGG MASSES LAID PER 100 PLANTS AND NUMBER OF FEMALE MOTHS IN FLIGHT, PER NIGHT, 1927–1936

The number of females in flight	Average number egg masses laid
1 – 10	2.2
10 – 20	4.9
20 – 30	16.0
30 – 40	6.7
40 – 50	11.4
75 – 100	27.1
100 – 200	30.9

From the above data and discussion, it would appear that when the temperature was in the neighbourhood of 57° F. to 59° F., there was some factor or factors operating which caused an inaccuracy in sampling in the flight and oviposition studies. The error is not serious.

There is a general agreement between the number of females in flight and the number of egg masses laid per 100 plants per night. This is shown in Table 8.

The lowered average for classes 30–40 and 40–50 are, no doubt, due to the few samples available. By far the most accurate records are those between 1 and 30 moths as for these there are many samples.

From these records, it can be seen that there is an increase in the number of egg masses laid with an increase in the number of females in flight. The increase is not a direct one. This may be due to the methods of sampling moths and eggs, or it is quite probable that a number of the moths in flight each night do not lay eggs. The percentage of non-laying moths may increase more rapidly than those laying eggs. Caffrey (4) has shown that under insectary conditions moths do not lay eggs during 30% of their oviposition period. This may also be true in the field and if so, would help to explain the phenomena discussed above.

The average number of egg masses laid per 100 plants for the class 1–10 females per night for each year is interesting as it shows that the same number of moths did not lay the same number of eggs each year.

TABLE 9.—AVERAGE NUMBER OF EGG MASSES LAID BY FROM 1–10 FEMALES PER 100 PLANTS PER NIGHT, 1927–1936

Year	Average number of egg masses	Year	Average number of egg masses
1927	1.8	1932	3.0
1928	1.0	1933	1.7
1929	2.4	1934	1.0
1930	4.9	1935	2.8
1931	1.2	1936	3.2
Average			2.2

From these records it would appear that 1930 was the best year for egg laying, followed by 1936 and 1932. Before evaluating the years, however, the number of eggs per mass has to be considered. This has been done in Table 6, which shows the true relationships of the various years in regard to egg production.

Eggs have been found in the field before, on the same date, and later than the date of first moths, but the variation in time of discovery was within a day or two. In most years, moths and eggs have been found upon the same date.

The dates of peak of flight and of egg laying do not coincide, the peak of oviposition being later by a varying number of days, each year.

TABLE 10.—SHOWING RELATIONSHIP OF PEAK OF FLIGHT AND PEAK OF OVIPOSITION CHATHAM, ONTARIO, 1927–1936

Year	Date of apparent peak of flight	Date of apparent peak of oviposition	No. of days oviposition peak is after flight peak
1927	July 12	July 14	2
1928	July 16	July 20	4
1929	July 7	—	—
1930	July 8	July 13	5
1931	July 9	July 6	3 before
1932	July 7	July 16	9
1933	June 29	June 30	1
1934	July 12	July 13	1
1935	July 11	July 13	2
1936	July 9	July 11	2
Average date	July 9	July 16	3

There is also a seasonal variation in the number of days necessary to arrive at the peaks of flight and oviposition as is shown in Table 11. It can be concluded from these data that in some years the type of season is equally favourable to the development of flight and oviposition as in the years 1933 and 1934, while in others it would appear that the season was earlier more favourable for oviposition than for flight. This was the case in 1931 and to some extent in 1936. In the other years, 1927, 1928, 1930, 1932, and 1935, the season would appear to have been earlier more favourable to flight than to egg laying.

The abruptness with which the egg laying curve in 1933 reaches a peak is in marked contrast to the smoother more gradually rising curve of flight.

The Position on the Plant in Which Eggs Are Laid

As pointed out in the review of literature, it was not known until about 1919 that the eggs were deposited upon the under surface of corn leaves. Caffrey (4) states that eggs are usually laid on the under surface of corn leaves, but that they are sometimes laid upon the upper surface of the leaf, on culms, or more rarely on the husks of the ears. Spencer (17) in Elgin county, Ontario, in 1921 and 1923, found that the majority of the eggs were laid on the under surface of the leaf but that in 1922 they were frequently found on the upper surface. He claimed that eggs laid on the upper surface were killed by sunlight and did not hatch. Huber (10) found in 1927 that in Ohio 86.8% were laid on the under surface of the leaf.

TABLE 11.—THE RATE AT WHICH FLIGHT AND OVIPOSITION PEAKS ARE REACHED AFTER THEIR COMMENCEMENT

Year	No. days required—flight	No. days required—oviposition
1927	4	7
1928	9	14
1929	3	—
1930	9	14
1931	9	3
1932	9	19
1933	5	4
1934	13	14
1935	6	9
1936	11	8
Average	8	10

The position in which eggs are laid is of importance in influencing egg mortality from natural causes such as sunlight or mechanical dislodgment. Huber (10) has shown the mechanics and the ease by which egg masses may be dislodged from leaves. The position in which eggs are found is also of importance in the application of control measures, as sprays to kill the eggs must be directed upon them.

Eggs have been found by us in three positions on the corn plant: *(a)* on the under surface of leaves,

TABLE 12.—THE POSITION IN WHICH EGG MASSES ARE LAID UPON THE CORN PLANT. PERCENTAGE OF TOTAL EGG MASSES PER SEASON, CHATHAM, ONTARIO, 1927–36

Year	Lower surface of leaf	Upper surface of leaf	Culm
1927	95.7	2.8	1.5
1928	97.6	1.2	1.2
1929	93.2	6.8	0.0
1930	98.1	1.9	0.0
1931	94.0	6.0	0.0
1932	86.5	10.7	2.8
1933	95.9	4.1	0.0
1934	92.0	8.0	0.0
1935	93.4	6.6	0.0
1936	98.0	2.0	0.0

(b) on the upper surface of leaves and *(c)* on the culm or stalk. The percentage of eggs found in these locations in various years is given in Table 12.

Egg masses at Chatham are usually laid upon the lower surface of the corn leaf. A few each year are laid upon the upper surface, but only rarely are they laid on the culm. A larger percentage is laid on the lower surface of the leaf than was the case cited by Huber in Ohio in 1927.

The Length of the Incubation Period

Huber (10) has reported that the length of the incubation period under insectary conditions in Ohio in 1927 varied from 4.7 to 10.5 days, with an average duration of 7.5 days. Caffrey (4) at Silver Creek, New York, found the period to average 6.3 days in length in 1923 and 6.4 days in length in 1924. These determinations were also made under insectary conditions. Poos (15) also working in Ohio, under insectary conditions, found the period varied from 4 to 9 days, with an average duration of 5.4 days. Bottger and Kent (2) measured the length of the incubation period in caged material in southern Michigan and obtained the following records:

Year	*Average duration in days*	*Year*	*Average duration in days*
1926	6.2	1929	6.4
1927	6.1	1930	5.6
1928	5.9	Average	6.1

The incubation period was measured in the field at Chatham. The observations were made each day except in 1935 and 1936 when they were made every other day, thus leaving a choice of one day in the duration of period.

TABLE 13.—LENGTH OF INCUBATION PERIOD IN DAYS, CHATHAM, ONTARIO, 1928–1936

Year	Shortest duration	Longest duration	Average duration
1928	4	10	7.1
1929	4	9	6.1
1930	3	8	6.1
1931	4	8	6.6
1932	2	12	6.4
1933	2	8	7.0
1934	5	8	6.5
1935	5 or 6	7 or 8	6.2 or 7
1936	3 or 4	9	5.4 or 6.2
Average	3.5 or 3.7	8.7	6.3 or 6.5

The incubation period as determined in the field is very close to that found by other workers under insectary conditions in various parts of North America. The average duration has been uniform in length for the 9-year period.

EGG MORTALITY AND SURVIVAL

Review of Literature and Summary

The factors causing egg mortality are very inadequately known. The only fundamental work upon factors causing egg mortality is that of Springer (18) on the effect of ultra violet light.

The factors which have been suggested as influencing egg mortality may be grouped into two main groups:

(a) Biotic factors, including degree of fertility, predators and parasites.

(b) Physical and mechanical factors, including high temperature, low humidity, desiccation, light and mechanical dislodgment from leaf.

Fertility of Eggs

The actual number of eggs which were not fertilized and therefore did not hatch is very difficult to determine from the literature, as the term "fertility" has apparently been used loosely. Spencer (17) working in Ontario in 1921 and 1922, under insectary conditions, found that 100% of the eggs under observation hatched in 1921 and 99% hatched in 1922. Caffrey (4) states that 91.5% of the eggs deposited in the insectary and 95.4% of those in the field were fertile. These determinations were made with the bivoltine type of borer. Poos (15) in Ohio, found that 98% of eggs in insectary and 99.3% in the field hatched in 1924. Huber (10) in Ohio, states that 97.9% are fertile. Bottger and Kent (2) found that under insectary conditions during 1926 to 1930, in southern Michigan, 94.9% of eggs were fertile. Hergula (9) on the other hand, found that only 65.9% of the eggs observed by him hatched in an insectary in Hungary.

If an average is taken of the North American records, it is found that 96.2% of the eggs hatch.

Predators and Parasites

Huber (10) is the only author giving data on egg mortality from this cause in the field. He found that 2.8% of eggs were destroyed by predators No figures are available for the number of eggs killed by parasites.

Temperature and Humidity

High temperatures, low humidities and desiccation have all been suggested as causing egg mortality. Huber (10) has, in a manner, shown that desiccation kills eggs, but no experimental work has been done. Springer (18) found in his work on ultra violet light that a temperature of 90° F. for 30 minutes killed 37% of eggs.

Light

Light has been suggested as a cause of death of eggs, but no work except Springer's has been done to determine whether the killing agency is light or heat or both. Spencer (17) as early as 1922, claimed that egg masses laid upon the upper surface of leaves were exposed to sunlight and consequently killed. Caffrey (4) also records that eggs exposed experimentally to the direct rays of sun failed to hatch, but no details are given. Flint (8) makes the statement that in Ohio 3 times as many eggs were laid in 1930 as in 1929, but that drought (dry, hot weather) withered and coiled the corn leaves exposing eggs to direct rays of sun and killing them. Springer (18) studied the effect of ultra violet light upon corn borer eggs and found that an exposure of 30 minutes killed 63% of the eggs.

Mechanical Dislodgment from Leaf

Huber (10) suggests that as the leaf rolls and unrolls in response to climatic factors, the motion of the leaf tends to loosen the egg mass and causes its dislodgment. High temperatures, wind and lashing movement of leaves in wind, facilitate the process. He found that 11.2% of eggs were dislodged in Ohio.

Davis (6) claims that the season of 1934 definitely set back the borer several years in the drought areas of the central west. The hot, dry winds

in the early season resulting in the curling of corn leaves and the dislodgment (peeling) of egg masses while continuous dry weather was very destructive to the young larvae.

Egg Mortality and Survival at Chatham

Egg mortality for the purposes of presentation has been divided into two divisions: *(a)* egg mortality caused by dislodgment of egg mass from the plant and *(b)* mortality in egg masses remaining upon the plants. In reality the egg mortality from dislodgment is perhaps not egg mortality in its true sense as eggs may hatch even if dislodged. What actually happens to eggs dislodged from plant is not known. Bartley and Scott (1) determined that for egg masses dropped experimentally to ground only 6% of the larvae were able to find the corn plant and mature. For the purposes of this paper, eggs dropping from plants are regarded as dead and counted as egg mortality.

Mortality and Survival from Dislodgment

The mortality (loss) of eggs due to dislodgment is shown at Chatham in Table 14. On July 13, 1932, a local hail storm lacerated the leaves of

TABLE 14.—EGG MORTALITY AND SURVIVAL DUE TO DISLODGMENT OF EGGS FROM PLANTS, PERCENTAGE OF TOTAL EGGS LAID

Year	No. egg masses dislodged	No. eggs dislodged	Per cent mortality	Per cent survival
1928	1	11	1.0	99.0
1929	4	43	6.6	93.4
1930	3	35	3.9	96.1
1931	1	6	2.6	97.4
1932	11	204	*26.5 (16.6)	73.5 (83.4)
1933	6	101	11.7	88.3
1934	3	46	34.0	66.0
1935	2	39	13.6	86.4
1936	3	19	2.4	97.6

* In 1932, as pointed out below, a local hail storm lacerated corn leaves, causing an increased mortality. The figure in brackets indicates what the mortality would have been if the storm had not occurred.

corn in our plots. At the time of its occurrence, 12 egg masses were on the plants being observed and 7 were destroyed by the storm. The 7 masses contained 76 eggs. The storm destroyed 58.3% of the egg masses, and 9.9% of the eggs laid during the entire season. If the storm had not occurred the egg mortality for the season due to dislodgment of eggs would have been 16.6%.

The Time of Season in Which Egg Masses Were Dislodged

The number of egg masses falling from plants is so small that little can be ascertained about the conditions causing them to fall. In 1928, one egg mass fell on July 11. In 1929, egg masses fell off on July 16, July 25 (2) and July 29. In 1930, they fell off July 10 and July 28 (2). In 1931, on July 5. In 1932, on June 29, July 6, July 13 and July 21. In 1933, on June 30, July 1, July 2, July 7, July 8, July 16. In 1934, on June 30 and July 13 (2). In 1935, on July 17 and July 23. In 1936, on July 19 (2) and July 22.

Two masses fell off on July 25, 1929; July 28, 1931; July 13, 1934; July 19, 1936. This might indicate that conditions at these times were favourable for egg mass dislodgment. The days under discussion in 1929, 1931 and 1934, were not particularly warm, but it rained on each one. July 19, 1936, was a very hot day, the temperature reaching 102° F. in the shade. Under this condition, corn would be wilted.

The Egg Mortality Upon Plants

The mortality of eggs remaining upon plants is smaller than that caused by eggs falling from plants. This may be seen from Table 15.

TABLE 15.—MORTALITY AND SURVIVAL OF EGGS REMAINING UPON PLANTS. PERCENTAGE OF TOTAL EGGS LAID FOR SEASON

Year	Mortality	Survival	Year	Per cent Mortality	Per cent Survival
1928	3.7	96.3	1933	5.6	94.4
1929	2.0	98.0	1934	0.0	100.0
1930	6.0	94.0	1935	8.1	91.9
1931	7.7	92.3	1936	11.6	88.4
1932	7.6	92.4	Average	5.8	94.2

The causes of the above mortality are not known. It is not, however, due to parasites or predators as the eggs were examined daily with a hand lens. The eggs failing to hatch were intact, but sometimes shrivelled and cometimes of a brownish colour. Infertile eggs were not distinguished. Only rarely was it that an entire egg mass failed to hatch.

This egg mortality occurred at various times during each season. The following is a record of the date upon which egg masses were laid and which experienced mortality. Each date represents an egg mass. When there are more than one on a single day, the number of masses is indicated in brackets. In the year 1928, July 11, 14, 15, 17, 18 (3). In 1929, July 4-14 (2), 21, 23, 25. In 1930, July 1, July 4 (2), 6 (4), 8, 13 (2), and July 16. In 1931, July 12. In 1932, June 30, July 9, 10, 11, 12, 13, 15, 16 (3), 27, 28, 31. In 1933, June 27, June 29 (6), July 1 (2), 5, 18, 26. In 1935, July 13 (2), 15, 21, 23, 31. In 1936, July 3, 5, 9, 11 (6), 13, 15 (3), 16, 17 (5).

The Mortality of Egg Masses Deposited on Upper Surface of Leaves

As has been shown and discussed above, a number of workers have observed that eggs exposed to direct sunlight are killed.

The number of egg masses laid on the upper surface of leaves during our observations has been small. Only 34 masses were laid on the establishment plot proper where detailed records of hatching were observed.

Only one mass was dislodged from the leaf. The mortality of eggs in masses remaining on the leaves was only 6.7% and the total mortality

counting the mass that fell off, during the 9 years was 15.2%. The egg mortality under our conditions was about the same in eggs laid on the upper surface as it was in those laid on the lower surface.

The Total Egg Mortality and Egg Survival

The egg mortality from all causes and based upon the total number of eggs laid during the season is shown in Table 16. In 1932, the mortality and survival are given with the hail storm mortality included, and in brackets the mortality as it would have been if the hail storm had not occurred.

Egg mortality was highest in 1934. It occurred by dislodgment of masses from plants as all eggs remaining on plants hatched. The lowest egg mortality occurred in 1928. The physical factors operating in these years will be discussed below.

TABLE 16.—TOTAL EGG MORTALITY AND SURVIVAL, CHATHAM, ONTARIO, 1928–1936, IN PERCENTAGE OF TOTAL EGGS LAID DURING SEASON

Year	Per cent mortality	Per cent survival
1928	4.8	95.2
1929	8.6	91.4
1930	9.8	90.2
1931	10.2	89.8
1932	32.2 (22.3)	67.8 (77.7)
1933	16.8	83.2
1934	34.1	65.9
1935	20.8	79.2
1936	13.9	86.1
Average	16.8 (15.7)	83.2 (84.3)

LARVAL MORTALITY AND SURVIVAL IN ESTABLISHMENT

A Review of the Literature

The literature referring to actual larval mortality and survival is not extensive. Usually, total mortality and survival of the egg and larval stages are considered together. An attempt is made to keep the two subjects separated for the present. Mortality and survival as a seasonal phenomenon is discussed later.

Spencer (17) working in Elgin county, Ontario, was the first to note and describe the enormous death rate of the larvae after hatching. In this case all of the eggs under observation hatched and egg mortality was not a factor. Spencer attempted to record the activities of larvae on corn plants immediately after hatching. He found that in 6 hours only 4 larvae out of 39 could be traced and were known to have remained upon the plant. Approximately one-tenth of all larvae remained on the plant; the others died or were blown from the plant. Some larvae curled up and died, without any apparent reason, within a few seconds after hatching.

Caesar (3) also working in Elgin county in 1924, studied larval mortality on four corn varieties. Here again there was no egg mortality and the results give larval mortality only. He found that the average mortality was 78.2% or a survival of 21.8%; 76.2% of the mortality occurred in the first two larval instars when the larvae were less than 10 days old. The factors responsible for larval mortality were not determined, but heavy rains, wind and other climatic factors and their seasonal variations were suggested as causes.

Painter (unpublished) studied the seasonal larval mortality at Harrow, Essex county, Ontario in 1923. He found that the average mortality for

3 types of corn was 84.4% or a survival of 15.6%. Painter and Ficht (13) repeated the work in Elgin county in 1924 and found the average mortality for the same 3 types of corn to be 80% which is a survival of 20%. They found that 75% of the mortality occurred in the first two larval instars "when the larvae were attempting to establish themselves". This is the first use of the term "establishment".

The causes of the death of larvae were not determined, but they noted that first instar larvae were quite helpless in a film of water and that many were drowned in the water present in the "throat" of the plant. They also found many larvae pinched to death between the surfaces of the leaves in the "throat" of the plant.

Caffrey (4) reported on work carried out at Sandusky, Ohio, in 1924. The larval mortality was 91.6% for the corn varieties studied. His work also showed that most of the mortality took place during the first 2 instars. He suggested that mortality was brought about by a variety of causes, the most important of which seemed to be desiccation, starvation and drowning.

Huber (10) pointed out that the meteorological factors, at the time the larvae are hatching and while they are yet outside the stalk, have a very important bearing upon the percentage of larvae becoming established. Fitful winds blow larvae from the plant, while stronger winds favour establishment because the larvae cling to the leaf surface. If, however, the temperature is low, about 60° F., the larvae are unable to cling to leaf surface for very long and they blow off. Dashing rains are also said by Huber to be destructive to larvae. He claims that still water in axils of leaves is harmless. This is contrary to the opinion of Painter and Ficht, noted above. The present writer has often noted numbers of dead larvae in the water in the axils of the leaves and assumed they had drowned. They might have blown in after dying on the leaf surface.

Roubaud (16) has shown that newly hatched larvae are extremely sensitive to dehydration. In a humid atmosphere, he found larvae would live a day comfortably without food, but if placed in a dry place they became sluggish and soon died.

Thompson and Parker (19) state that in the lower Rhone valley in Europe the corn fields are swept by a constant wind known as the "mistral". Only a slight corn borer infestation develops in this valley and it is thought that the reduced infestation is due to the effect of the wind on the adults and young larvae.

The above review indicates that larval mortality and survival varies somewhat, depending upon a number of biotic and climatic factors, and varies from 75 to 80% mortality or a survival of 20 to 25%. Various physical and climatic factors have been suggested as the causes of larval mortality, but no one has actually determined the causes.

Larval Mortality at Chatham

Larval mortality has been studied and measured in the field during the past 9 years. Table 17 shows the mortality and survival obtained. The actual larval mortality has varied from 92.4% in 1930 to as low as 42.8% in 1931. The average larval mortality has been 72.1%.

It has been shown by Caesar (3), Painter and Ficht (13), Caffrey (4) and others that mortality takes place immediately after the larvae hatch and before they enter the plant. The time of season in which larvae hatched in each year is shown in some detail later.

TABLE 17.—LARVAL MORTALITY AND SURVIVAL IN ESTABLISHMENT, CHATHAM, ONTARIO, 1928–1936

Year	No. eggs hatching	No. larvae recovered	Per cent larval mortality	Per cent larval[1] survival
1928	1041	455	56.2	43.8
1929	588	106	81.9	18.1
1930	795	60	92.4	7.6
1931	203	116	42.8	57.2
1932	522	129	75.2	24.8
1933	717	151	78.9	21.1
1934	89	25	71.9	28.1
1935	226	110	51.3	48.7
1936	667	203	69.5	30.5
Average			72.1	27.9

The Effect of the Physical Factors upon Larval Mortality and Survival

Wind, rain, and hot dry periods are among the physical factors suggested by various authors as causing high larval mortality. It is shown later that these three factors have not influenced the percentage of larval mortality to any extent at Chatham. Sudden heat waves have been the main factor causing larval mortality. A detailed discussion is given later.

TOTAL MORTALITY AND SURVIVAL

Egg and larval mortality and survival have been discussed individually above. They will now be discussed as total mortality and survival based upon the total number of eggs laid.

There are a few additional papers dealing with this phase of the study. Marshall (12) studied the total mortality at Aylmer, in Elgin county, Ontario, in 1926, by artificially infesting plants with egg clusters. He obtained an average mortality of 86.6% or a survival of 13.4%. Marshall was the first to attempt to show a correlation between total mortality and field infestation in the neighbourhood of his experimental plots. He utilized his own records and those of Caesar and others taken in Elgin county. He concluded that a high mortality foretells a decrease in field population.

Caffrey (4) states that in 1924 in northern Ohio, in caged experiments, the total mortality was 94.1%.

Patch (14) shows that at Sandusky, Ohio, the total mortality in all varieties of corn studied was 66% in 1927 and 64.4% in 1928. Thsee are survivals of 34 and 35.6% respectively. He points out that these figures are much lower (mortality) than the 85% average mortality obtained in previous years.

Ficht (7) gives the seasonal mortality for three varieties of corn grown at Monroe, Michigan, during certain years. The following summary

showing the percentage mortality has been arranged from a portion of his data.

Variety of Corn	*1928*	*1929*	*1930*
Clements White Cap	83.0	78.9	92.7
Johnson County White	84.6	81.5	94.6

The mortality and survival on these varieties at Monroe, Michigan, are practically identical with those obtained on Wisconsin No. 7 corn at Chatham during 1929 and 1930. The season of 1928 was much more favourable for borer survival at Chatham than it was at Monroe. This may be determined by comparing the results at Monroe with those obtained at Chatham as shown in Table 18.

TABLE 18.—TOTAL MORTALITY AND SURVIVAL, WISCONSIN NO. 7 CORN, CHATHAM, ONTARIO, 1928–36

Year	Total no. eggs laid	Total no. eggs hatching	Per cent egg mortality	No. larvae recovered	Per cent larval mortality	Per cent total mortality	Per cent total survival
1928	1093	1041	4.8	455	56.2	58.3	41.7
1929	*643	588	8.6	106	81.9	83.5	16.5
1930	881	795	9.8	60	92.4	95.4	4.6
1931	226	203	10.2	116	42.8	48.6	51.4
1932	769	522	32.2	129	75.2	83.2	16.8
1933	861	717	16.8	151	78.9	82.4	17.6
1934	135	89	34.1	25	71.9	81.4	18.6
1935	285	226	20.8	110	51.3	61.4	38.6
1936	774	667	13.9	203	69.5	73.7	26.3
Average			16.8		72.1	76.1	23.9

* The total eggs laid for this season was 765. Only a portion of these, namely, 643, were used for establishment records.

(To be continued)

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DIGESTIBILITY STUDIES WITH RUMINANTS.

III. PLANE OF NUTRITION AND DIGESTIBILITY OF MANGELS

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In the first paper of this series on *Digestibility Studies with Ruminants* (1) four factors which required study were listed. These were: *(a)* plane of nutrition; *(b)* associative effects; *(c)* age of animal; and *(d)* species. The first two, namely, plane of nutrition and associative effects are interrelated. Consider, for instance, a two-component ration such as hay and a succulent. If the hay is fed at a constant level and the quantities of succulent varied, then, not only will there be a change in the plane of nutrition, but there will also be a change in the ratio of succulent to hay.

The complete investigation of this condition requires: *(a)* a calculation of the digestibility of the succulent at each level of feeding with the hay kept at a constant level; *(b)* a determination of the effect of the plane of nutrition upon the digestibility of rations of hay and the succulent in which the components are in constant ratio to one another, several experiments being undertaken in which different ratios are used; and *(c)* a determination of the effect of the plane of nutrition upon the hay alone and the succulent alone. Depending upon the outcome of any one of these factors, it may or may not be necessary to investigate all three of them.

Two combinations have been studied in this way, namely, hay and corn silage, and hay and mangels. In the case of the former it was necessary to investigate all three factors. In the case of the latter, however, that has not been deemed necessary. The present paper reports the results with the hay and mangels combination, while the results with silage will be published later in a series of papers.

Before discussing the actual experiments, certain points in technique require explanation. These refer, first, to the method of conducting *ad libitum* feeding trials, and second, to the method of preparing mangels for a chemical analysis.

In conducting *ad libitum* feeding trials, roots at a level of 50 kilogrammes per animal per day were added to a constant hay ration up to and including the morning feeding of the first day of the collection period. They were then fed *ad libitum* up to and including the morning feeding of the fourth day before the end of the collection period. From this point, the level of roots was reduced to the 50 kilogrammes per day originally fed.

Two assumptions were made in conducting trials in this manner. The first was that not more than four days were required until the fecal excretion corresponded to the ration fed. The second was that the time required for the fecal excretion to correspond to the ration in going from the 50 kilogrammes to the *ad libitum* was the same as that required in going from the *ad libitum* to the 50 kilogrammes. Even if these assump-

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tions were not exact, the error must have been very slight since the level of 50 kilogrammes was close to the *ad libitum* feeding.

It is true, however, that apart from the operating difficulties in carrying out such a trial, the method itself does not, theoretically, conform to recognized good practice in conducting digestibility trials. For dry feeds, therefore, the maximum constant level which can be consumed should be ascertained in the preliminary period and that level fed throughout the trial. The *ad libitum* feeding is perhaps more justified with roots or succulents since there is, in any case, a variation in dry matter content of the daily rations, thus prohibiting a constant intake throughout the experiment.

To prepare air-dry samples of roots for analysis, care must be taken to avoid losses of "soluble carbohydrates" through enzymatic action. In an oven at 70° C., the temperature of the root cuttings does not apparently reach a sufficiently high degree in the initial stages to inhibit this enzymatic action. This is indirectly illustrated in the following experiments.

Dry matter determinations were made on cuttings of mangels under the following conditions: *(a)* dried at 100° C. to a constant loss; *(b)* dried for 18 hours at 70° C. followed by drying at 100° C. to a constant loss; and *(c)* procedure *(b)* with the roots first treated with chloroform to eliminate bacterial action. The results are given in Table 1.

TABLE 1.—DRY MATTER CONTENTS OF MANGELS AS DETERMINED BY DIFFERENT PROCEDURES

Sample No.	Dry matter contents		Differences
	At 100° C.	Preliminary at 70° C.	
	%	%	
1	10.75	10.24	+0.51
2	10.77	9.00	+1.77
3	11.29	10.38	+0.91
4	9.55	9.29	+0.26
5	10.30	10.08	+0.22
6	11.61	8.23	+3.38
7	11.15	10.93	+0.22
8	11.11	8.71*	+2.40
9	11.08	10.17*	+0.91
Means	10.85	9.67	+1.176

* Treated with chloroform. $t = 3.162$.

It will be noticed from Table 1 that when the roots were placed in the oven at a temperature of 70° C. there was a loss of dry matter. Enzymatic action presumably caused this loss since the treatment with chloroform in the two cases tried did not affect the results. The magnitude of the losses showed considerable variation depending possibly upon the position in the oven and the rapidity of drying. Using Fisher's t test, however, the differences were statistically significant.

To serve as a check on the oven drying method at 100° C., dry matter determinations were made on the roots by means of the xylene distillation method. The results are expressed in Table 2.

In 6 out of the 9 comparisons, the results with the xylene distillation method were slightly higher than with the oven drying. The mean of the dry matters determined by the xylene method was slightly higher than the mean determined by the overn drying. The difference, however, was not statistically significant.

This tendency for the xylene method to give slightly higher results might be due in part to a loss of a small amount of water either in the

condenser or entrained with and carried back by the xylene to the distillation flask. This flask was of 1-litre capacity, and 300 to 400 cubic centimetres of xylene on 120 grammes of roots were used. A loss of 0.19 cc. of water would produce the differences in dry matter content shown in the table above. These differences may also be due in part to occasional losses of dry matter even at 100° C. It was felt, however, that these results substantiated the trustworthiness of the oven drying at 100° C. and that, therefore, the results obtained by a preliminary drying at 70° C. were too low.

TABLE 2.—DRY MATTER CONTENTS OF ROOTS DETERMINED BY OVEN DRYING AT 100° C. AND BY XYLENE DISTILLATION

Sample No.	Dry matter contents		Differences
	At 100° C. in oven	Xylene distillation	
	%	%	
1	10.16	10.34	−0.18
2	9.83	10.39	−0.56
3	10.13	10.71	−0.58
4	9.94	9.72	+0.22
5	9.90	9.85	+0.05
6	10.07	10.18	−0.11
7	9.40	9.78	−0.38
8	9.80	9.65	+0.15
9	9.66	9.73	−0.07
Means	9.88	10.04	−0.162

$t = 1.675$.

For preparing samples of roots, other succulents, and feces for analysis, therefore, the following procedure was adopted. The samples in large shallow enamel trays were placed in an oven at 100°C. for $1\frac{1}{2}$ to 2 hours to inhibit enzyme action. They were then placed in the oven at 70° C. and brought to dryness. It should be pointed out that water in a flat dish in the oven at 100° C. reached a temperature of approximately 70° C. in three-quarters of an hour and remained constant at that temperature. It was felt, therefore, that this preliminary treatment of the samples was sufficient to prevent enzyme action.

Even under these conditions there seems to have been a slight loss or slight decomposition of the "soluble carbohydrates". The nitrogen contents of the roots calculated from the analyses of the air-dried samples were always slightly higher than the nitrogen contents calculated from determinations on the original samples. In the calculation of the coefficients of digestibility, the analyses of the air-dried samples have been used as the basis.

EXPERIMENTAL PROCEDURE

The experimental animals consisted of four grade Shorthorn steers, numbered in the experiment A, B, C and D, with average weights for the whole experiment of 489, 497, 447 and 444 kilogrammes respectively. Nine rations were fed, namely, hay alone, mangels alone, and mixtures of mangels and hay in which the hay was kept constant at 4 kilogrammes per animal per day and the mangels were fed at levels of, 5, 10, 16, 22, 35, 50 and *ad libitum* kilos per animal per day. The experiment lasted 18 months and consisted of 12 periods. The first 7 periods were carried out in 1935–36 and the last 5 in 1936–37. Between these two seasons the animals were placed on pasture for three months. The same hay was used throughout the entire experiment. It was necessary, however, to use mangels from

two crops. They were, nevertheless, from the same locality, of the same variety, and grown as far as possible under similar conditions. The schedule of the experiment is given in Table 3.

TABLE 3.—SCHEDULE OF EXPERIMENT (WEIGHTS IN KILOGRAMMES PER DAY)

Period No.	Feeding stuff	Fed per day per animal			
		Animal A	Animal B	Animal C	Animal D
1935–36					
1	Hay	4	4	4	4
	Mangels	5	10	16	22
2	Hay	4	7.5	0	4
	Mangels	61*	0	28	5
3	Hay	4	4	4	4
	Mangels	10	50	22	52.2*
4	Hay	7.5	0	4	4
	Mangels	0	40	35	10
5	Hay	4	4	4	7.5
	Mangels	50	22	54.2*	0
6	Hay	0	4	4	4
	Mangels	40	35	10	50
7	Hay	—	—	7.5	—
1936–37					
8	Hay	7.5	4	4	0
	Mangels	0	16	50	40
9	Hay	4	7.5	0	4
	Mangels	22	0	40	35
10	Hay	0	4	7.2	4
	Mangels	40	5	0	16
11	Hay	4	4	4	7.5
	Mangels	16	58.3*	5	0
12	Hay	4	0	—	0
	Mangels	35	40	—	40

* *Ad libitum* feeding of mangels.

It will be observed from Table 3 that each animal received each hay-mangel ration once, and each of the rations of hay alone or mangels alone, twice. Iodized rock salt was given *ad libitum* in the preliminary periods and iodized granulated salt in the collection periods at a rate of 20 grammes per animal per day for all rations containing roots, and at a rate of 30 grammes per day for the hay rations.

Each complete digestion trial lasted 28 days. The first four days constituted the pre-experimental feeding, the ensuing twelve were the preliminary, and the final twelve the collection. During the pre-experimental feeding, the animals received a good ration of hay, mangels, and

3 kilos of the following grain mixture: ground oats 400, ground barley 300, gluten meal 100, wheat bran 100, oil cake 100, bone char 20 and salt 10. The animals were also exercised at this time. When a collection period of 16 days was used for *ad libitum* trials, this pre-experimental period was omitted.

Dry matter and nitrogen were determined daily on the feces during 1935–36 and every 2 days during 1936–37. Dry matter was determined daily on the roots during the entire experiment and nitrogen was determined daily during 1936–37.

Sufficient hay to last the entire experiment was stored in the barn loft. For each trial, approximately three-quarters of a ton were cut in a corn cutter and thoroughly mixed. Individual daily rations for the entire trial were bagged. During the bagging, four samples of about 4 kilogrammes each were taken for analysis.

In the case of Animal C, period 10, there was a refusal of hay amounting to 4%. This took place at the beginning of the collection period, but during the latter part the animal ate its ration completely. In Table 4, the composition of the refused material is compared with that of the experimental hay.

TABLE 4.—COMPARISON OF CHEMICAL COMPOSITION OF EXPERIMENTAL HAY AND REFUSED HAY IN PERIOD 10 ON DRY MATTER BASIS

Nutrient	Refused hay	Experimental hay
	%	%
Ash	7.83	7.77
Crude protein	11.44	12.48
Ether extract	1.78	2.19
Crude fibre	39.03	36.99
N-free extract	39.92	40.57

The refused hay was slightly higher in crude fibre and slightly lower in crude protein than the experimental. Presumably, in the refused sample there was less leafy material. However, this refused material as indicated by the chemical analysis and also by its appearance quite closely resembled the original hay. It was concluded that the coefficients of digestibility determined in this case were reliable.

RESULTS

In Table 5 are given the chemical compositions of the hay for the individual periods and for the individual samples within those periods.

TABLE 5.—CHEMICAL COMPOSITIONS OF HAY IN PERCENTAGE OF DRY MATTER

Sample No.	Percentage composition									General means
	Period 1	Period 2	Period 3	Period 4	Period 5	Period 6	Period 7	Periods 8 and 9	Periods 10, 11, 12	
Organic matter										
1	92.58	91.96	91.39	92.49	92.31	92.30	92.03	92.21	92.19	
2	92.44	91.56	92.06	92.30	92.47	92.16	91.60	91.78	91.88	
3	92.71	91.85	91.74	92.11	91.89	92.09	91.92	91.99	92.20	
4	92.31	91.35	91.77	92.06	92.14	92.15	92.03	91.90	92.63	
Means	92.51	91.68	91.74	92.24	92.20	92.17	91.89	91.97	92.23	92.071

TABLE 5.—CHEMICAL COMPOSITIONS OF HAY IN PERCENTAGE OF DRY MATTER—*Continued*

Sample No.	Percentage composition									General means
	Period 1	Period 2	Period 3	Period 4	Period 5	Period 6	Period 7	Periods 8 and 9	Periods 10, 11, 12	
Nitrogen										
1	1.82	1.98	2.06	1.86	1.93	1.87	2.00	1.95	2.08	
2	1.91	2.17	1.89	1.96	1.88	1.98	1.92	2.06	1.96	
3	1.80	2.07	1.94	1.97	2.13	1.93	2.09	2.06	2.03	
4	1.94	2.15	1.98	2.11	1.92	1.96	2.11	2.00	1.92	
Means	1.87	2.09	1.97	1.97	1.96	1.93	2.03	2.02	2.00	1.983
Ether extract										
1	1.78	1.90	1.96	1.84	1.74	1.82	1.68	2.12	2.23	
2	1.69	1.98	1.63	1.73	1.70	1.69	1.93	2.36	2.29	
3	1.91	1.73	1.94	1.82	1.83	1.69	1.77	2.26	2.17	
4	2.11	2.00	1.90	1.96	1.83	1.67	1.82	2.21	2.08	
Means	1.87	1.90	1.86	1.84	1.78	1.72	1.80	2.24	2.19	1.910
Crude fibre										
1	39.13	37.36	35.97	38.11	39.69	37.35	36.75	38.37	37.77	
2	38.84	35.65	37.87	39.26	38.96	38.60	34.85	36.07	36.11	
3	38.59	37.82	36.67	38.26	36.74	37.55	35.96	37.45	36.54	
4	37.11	35.19	36.34	37.25	37.21	38.57	36.11	37.45	37.57	
Means	38.42	36.51	36.71	38.22	38.15	38.02	35.92	37.34	36.99	37.364
N-free extract										
1	40.27	40.34	40.56	40.92	38.80	41.45	41.13	39.55	39.17	
2	39.96	40.36	40.73	39.09	40.05	39.52	42.83	40.49	41.26	
3	40.96	39.34	41.01	39.74	40.03	40.81	41.15	39.41	40.80	
4	40.99	40.72	41.15	39.68	41.11	39.68	40.93	39.73	40.99	
Means	40.54	40.19	40.86	39.85	39.99	40.36	41.50	39.79	40.57	40.409

TABLE 6.—ANALYSIS OF VARIANCE OF CHEMICAL COMPOSITION OF HAY

For $n_1 = 8$, $n_2 = 27$ at P of 0.05, $z = 0.4176$ and at P of 0.01, $z = 0.5902$

Nutrient	Variance due to	F	Sums of squares	Variance	$\frac{1}{2}$ Log_e variance	z
Organic matter	Within periods	27	1.3783	0.05105	2.5125	0.8672
	Between periods	8	2.3136	0.28920	$\bar{1}$.3797	
Nitrogen	Within periods	27	0.1753	0.00649	$\bar{3}$.4815	0.4471
	Between periods	8	0.1270	0.01588	$\bar{3}$.9286	
Ether extract	Within periods	27	0.3569	0.0132	$\bar{3}$.8370	1.1459
	Between periods	8	1.0460	0.1308	$\bar{2}$.9829	
Crude fibre	Within periods	27	25.1973	0.9332	$\bar{1}$.9654	0.6081
	Between periods	8	25.1145	3.1393	0.5735	
N-free extract	Within periods	27	14.7685	0.5470	$\bar{1}$.6983	0.3840
	Between periods	8	9.4333	1.1792	0.0823	

In Table 6 an analysis of the variance of the results is presented. The variance within the periods has been compared with the variance between the periods. With the exception of the nitrogen-free extract and perhaps the nitrogen, the variance between the periods was statistically significantly greater than the variance within the periods. This was to be expected since the portion of hay for each period was thoroughly mixed whereas the hay stored for the entire experiment was, of course, not previously mixed. The means for the periods were, however, quite uniform, showing no particular trend and revolving regularly around the general means.

In Table 7, the chemical composition of the 1935–36 crop of mangels has been compared with that of the 1936–37 crop. The means, standard

TABLE 7.—CHEMICAL COMPOSITION OF MANGELS IN 1935–36 AND 1936–37 IN PERCENTAGE OF DRY MATTER

Period No.	Organic matter	Nitrogen	Ether extract	Crude fibre	N-free extract
			1935–36		
1	90.18	2.14	0.51	8.30	67.99
2	89.40	2.05	0.57	7.51	68.53
3	88.85	2.28	0.92	8.48	65.19
4	89.36	2.20	0.95	8.76	65.87
5	89.45	2.21	0.78	8.09	66.80
6	89.78	2.25	0.68	8.60	66.42
Mean	89.50	2.19	0.74	8.29	66.80
Standard error	±0.18	±0.03	±0.07	±0.18	±0.52
Coefficient of variation	0.50	3.79	24.5	5.40	1.90
			1936–37		
8	88.03	2.17	0.52	9.04	64.90
9	87.37	2.16	0.49	8.94	64.47
10	88.38	2.23	0.52	9.18	64.76
11	90.82	1.94	0.51	7.27	70.94
12	90.67	1.91	0.94	7.27	70.51
Mean	89.05	2.08	0.60	8.34	67.12
Standard error	±0.71	±0.07	±0.09	±0.44	±1.48
Coefficient of variation	1.78	7.02	32.2	11.76	4.92

errors and coefficients of variation have been calculated. It is quite evident that there were no differences in chemical composition between the crops of the two years.

In Table 8, the coefficients of digestibility of the hay and mangels determined when each was the sole feed have been compared for the 1935–36 and the 1936–37 periods. The results for the two years with both feeds were quite similar. Only in the case of the coefficients of digestibility of the nitrogen of the mangels did it appear that the 1935–36 crop differed to some extent from the 1936–37 crop. It should be noted, of course, that only three values were available for the 1935–36 crop which fact made the mean somewhat unreliable as an estimate of the true value.

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TABLE 8.—COMPARISON OF COEFFICIENTS OF DIGESTIBILITY OF HAY AND MANGELS FOR 1935–36 AND 1936–37
(Coefficients in per cent)

Animal No.	Feeding stuff	Dry matter		Organic matter		Nitrogen		Ether extract		Crude fibre		N-free extract	
		1935–36	1936–37	1935–36	1936–37	1935–36	1936–37	1935–36	1936–37	1935–36	1936–37	1935–36	1936–37
A	Hay	52.0	52.5	52.9	53.5	58.1	58.6	43.9	48.9	43.0	42.1	60.8	61.8
B		52.1	52.7	52.9	53.4	58.6	59.8	35.2	50.8	43.3	42.9	59.7	60.7
C		52.2	53.0	53.0	53.5	56.1	55.0	33.9	50.5	39.7	42.2	63.4	62.6
D		51.4	51.7	52.1	52.5	57.9	55.5	34.0	44.4	40.8	42.0	61.1	60.6
Mean		51.9	52.5	52.7	53.2	57.7	57.2	36.8	48.7	41.7	42.3	61.3	61.4
S.E.		±0.18	±0.28	±0.21	±0.24	±0.55	±1.17	±2.40	±1.48	±0.87	±0.20	±0.78	±0.48
C.V.		0.70	1.06	0.80	0.91	1.89	4.09	13.1	6.07	4.17	0.97	2.54	1.55
A	Mangels	87.0	87.1	87.8	88.3	76.6	73.2			57.9	65.1	94.5	95.3
B		86.7	87.3	88.7	89.4	75.3	72.2			59.8	62.3	95.8	95.5
C		85.1	84.0	86.6	85.5	79.2	73.0			25.5	46.7	95.0	94.0
D			87.0		89.0		78.4				61.7		95.3
D			84.3		86.6		65.7				48.7		94.2
Mean		86.3	85.9	87.7	87.8	77.0	72.5			47.7	56.9	95.1	94.9
S.E.		±0.59	±0.73	±0.61	±0.74	±1.15	±2.02					±0.38	±0.31
C.V.		1.18	1.91	1.20	1.89	2.58	6.24					0.69	0.74

From the results, then, of the chemical compositions and digestibilities of the hay and mangels as presented in Tables 5, 6, 7 and 8, it was concluded that the feeds were the same in both years and that the experiment could be treated as one continuous investigation.

Using the average coefficients of digestibility determined from the eight trials with hay, the coefficients of digestibility of the mangels have been calculated from the 28 mixed rations. Since in a previous publication (1) it was shown that the plane of nutrition had no effect on the digestibility of hay, then the coefficients of digestibility of the nutrients of the hay determined on the hay alone at a level of 7.5 kilogrammes per day were applicable to the four kilogrammes of hay fed in the mixed rations. The complete data will be found in Table 11 in the appendix. In Table 9, the calculated coefficients of digestibility of mangels as well as the coeffi-

TABLE 9.—COEFFICIENTS OF DIGESTIBILITY OF MANGELS ARRANGED BY ANIMALS AND BY RATIONS (COEFFICIENTS IN PER CENT)

Nutrient	Animal	Determined directly		Calculated from mixtures with hay							Means
		M	M_1	I	II	III	IV	V	VI	VII	
Dry matter	A	87.0	87.1	88.0	84.2	85.2	88.0	87.6	85.1	83.2	86.2
	B	86.7	87.3	94.8	86.1	90.1	85.9	84.2	83.0	83.2	86.8
	C	85.1	84.0	82.9	77.7	87.2	85.3	86.7	82.0	88.6	84.4
	D	87.0	84.3	78.2	82.5	83.1	85.4	89.7	84.4	83.8	84.3
	Means	86.5	85.7	86.0	82.6	86.4	86.2	87.1	83.6	84.7	85.41
	S.E.	±0.46	±0.88	±3.56	±1.80	±1.49	±0.63	±1.34	±0.70	±1.31	
	C.V.	1.06	2.06	8.27	4.36	3.45	1.46	2.62	1.67	3.09	
Organic matter	A	87.8	88.3	91.0	87.8	87.4	89.7	90.0	86.6	85.2	88.2
	B	88.7	89.4	96.2	90.0	92.5	87.1	84.1	85.7	85.6	88.8
	C	86.6	85.5	85.8	78.0	89.0	87.7	88.4	84.2	89.5	86.1
	D	89.0	86.6	79.6	82.9	84.6	87.0	91.1	84.9	85.8	85.7
	Means	88.0	87.5	88.2	84.7	88.4	87.9	88.4	85.4	86.5	87.20
	S.E.	±0.54	±0.87	±3.55	±2.68	±1.65	±0.63	±1.54	±0.52	±1.00	
	C.V.	1.23	1.99	8.06	6.32	3.73	1.43	3.48	1.21	2.31	
Nitrogen	A	76.6	73.2	70.4	63.6	61.7	73.1	65.3	69.1	64.3	68.6
	B	75.3	72.2	92.4	73.4	83.6	74.4	75.4	66.9	60.8	74.9
	C	79.2	73.0	66.9	74.3	75.5	70.6	71.7	62.2	68.6	71.3
	D	78.4	65.7	81.9	72.6	63.6	70.0	76.2	69.6	67.7	71.7
	Means	77.4	71.0	77.9	71.0	71.1	72.0	72.2	67.0	65.4	71.65
	S.E.	±0.88	±1.79	±5.80	±2.48	±5.17	±1.04	±2.49	±1.69	±1.78	
	C.V.	2.27	5.04	14.89	6.99	14.53	2.88	6.88	5.04	5.43	
N-free extract	A	94.5	95.3	93.9	93.5	93.3	96.2	95.9	94.3	92.7	94.4
	B	95.8	95.5	102.4	98.2	95.3	94.3	93.0	92.5	92.4	95.5
	C	95.0	94.0	95.1	92.4	94.4	93.7	94.6	91.9	95.1	94.0
	D	95.3	94.2	86.9	92.0	95.2	93.7	95.9	92.8	92.4	93.2
	Means	95.2	94.8	94.6	94.0	94.6	94.5	94.9	92.9	93.2	94.27
	S.E.	±0.27	±0.38	±3.17	±1.43	±0.46	±0.59	±0.69	±0.51	±0.65	
	C.V.	0.58	0.80	6.71	3.04	0.98	1.25	1.45	1.10	1.40	

cients determined directly with mangels as the sole feed have been arranged by rations and by animals. The coefficients of digestibility which were directly determined have been placed in columns M and M_1; M representing

the first cycle of the experiment and M_1 the second. The remaining columns headed by Roman numerals represent increasing quantities of mangels fed with the constant ration of hay. Columns VI and VII, representing 50 kilogramme and *ad libitum* levels, respectively, were actually very close together and the whole eight values may be taken as indicative of top levels of feeding.

The analysis of variance of these data is presented in Table 10.

TABLE 10—ANALYSIS OF VARIANCE OF COEFFICIENTS OF DIGESTIBILITY OF MANGELS WHEN ARRANGED BY RATIONS AND BY ANIMALS

For—$n_1 = 3$, $n_2 = 24$, then z is 0.5508 at 5% points, 0.7757 at 1%
$n_1 = 8$, $n_2 = 24$, then z is 0.4283 at 5% points, 0.6064 at 1%
$n_1 = 24$, $n_2 = 8$, then z is 0.5682 at 5% points, 0.8319 at 1%

Nutrient	Variance due to	F	Sums of squares	Variance	$\frac{1}{2}$ Log$_e$ variance*	z compared with error
Dry matter	Animal	3	43.28	14.43	1.3345	0.2042
	Ration	8	71.03	8.88	1.0918	0.0385
	Error	24	230.13	9.59	1.1303	
	Total	35	344.44			
Organic matter	Animal	3	63.18	21.06	1.5237	0.3229
	Ration	8	60.32	7.54	1.0101	0.1907
	Error	24	267.99	11.17	1.2008	
	Total	35	391.49			
Nitrogen	Animal	3	179.91	59.97	2.0469	0.2766
	Ration	8	537.53	67.19	2.1038	0.3335
	Error	24	827.65	34.49	1.7703	
	Total	35	1545.09			
N-free extract	Animal	3	24.73	8.24	1.0547	0.1603
	Ration	8	19.63	2.45	0.4489	0.4455
	Error	24	143.56	5.98	0.8944	
	Total	35	187.92			

* Data under "Sums of Squares" and "Variance" carried to four decimal places in making these calculations for dry matter and N-free extract.

The results for the calculated coefficients have been expressed graphically in Figure 1. In a graph of this type, constant digestibility is indicated by a straight line, and a decreasing digestibility by a curve concave downward.

In the statistical analysis, only four nutrients have been considered, namely, dry matter, organic matter, nitrogen and nitrogen-free extract. These should serve to characterize fully the trend of digestibility of the mangels. The ether extract is a negligible quantity in mangels and it is impossible to calculate its coefficients of digestibility. The coefficients of the crude fibre showed wide variations. This fact is illustrated in Figure 1. A statistical analysis did not, therefore, seem justified. As seen from the graph, however, a straight line seemed to express in the best manner the trend of the digestibility of this nutrient.

For the dry matter and organic matter, the coefficients of digestibility determined directly and calculated from rations I, III, IV and V can be considered identical. The values for rations II, VI and VII were slightly

lower than the others. Statistically, the differences between the means were not significant. It is possible, however, that at top levels there may be a slight lowering of the digestibility, perhaps to the order of 1%. Attention should be directed to the coefficients of variation for the individual means. At level I, these coefficients were rather high, but fell off rapidly

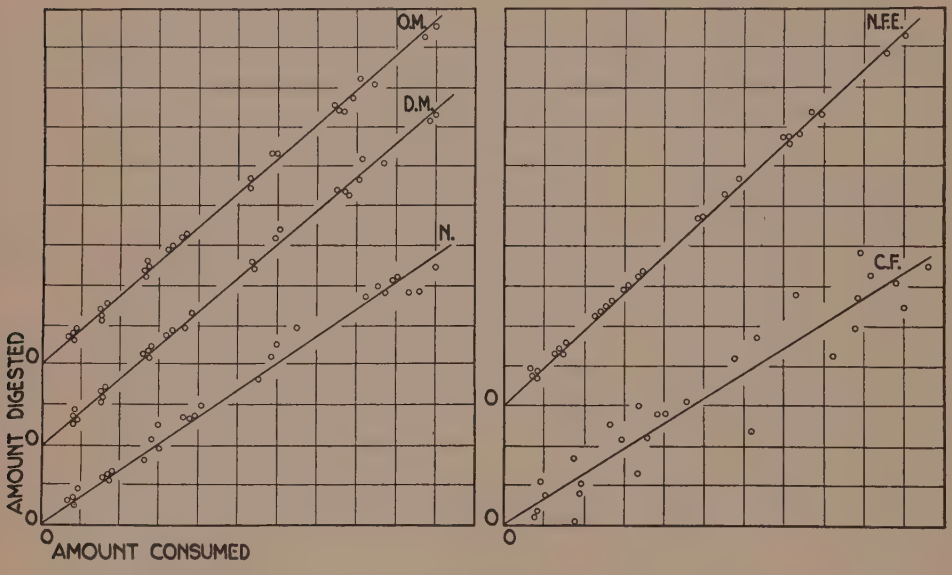

FIGURE 1.—Nutrients in mangels consumed. D.M. = Dry Matter; O.M. = Organic Matter; N. = Nitrogen; N.F.E. = Nitrogen-free Extract; C.F. = CrudeFibre; O. = Origin. The amount of nutrients consumed was calculated in kilograms and adjusted to a common scale for these graphs.

as the level of feeding increased. They were quite small for levels IV, V, VI and VII as well as for the mangels alone. The values for levels II and III were reasonably satisfactory. At level I, of course, when only 5 kilos of roots were fed with the four kilos of hay, the usual errors coincident with the calculation of coefficients of digestibility by difference were greatly magnified.

The means of the coefficients of digestibility of the nitrogen-free extract were remarkably uniform, though there was a slight lowering at the top levels. Statistically, the 36 values were homogenous thus substantiating the conclusions arrived at for the dry matter and the organic matter.

Considerable variation existed among the nitrogen values and in the case of rations I and III, the coefficients of variation were too large, being 14.89 and 14.63, respectively. At the top levels, the digestibility was somewhat lower, though not significantly so. However, more uniformity among the individual values would have greatly decreased the error with which the differences between periods were compared. Nevertheless, apart from the values at the top levels there was no evidence whatsoever that either the plane of feeding or the association with the hay affected the coefficients of digestibility.

It would seem, therefore, justifiable to consider the 36 values for the coefficients of digestibility of each of the three nutrients, dry matter,

organic matter and N-free extract, as homogeneous. Since they included values for mangels alone as well as for mixtures with a constant hay ration at all levels of feeding, then it follows that neither the plane of nutrition nor the association with hay affected the digestibility of the mangels. In the case of nitrogen, the possibility that there was a slight lowering of digestibility at the top levels cannot be excluded. For the remaining levels, however, the plane of nutrition had no effect. There was no associative effect.

SUMMARY

Digestion trials were conducted with four grade Shorthorn steers on the following rations: hay alone, mangels alone, and mixed rations of hay and mangels in which the hay was fed at a constant level of four kilogrammes per animal per day and the mangels at levels of 5, 10, 16, 22, 35, 50 and ad libitum kilogrammes per animal per day.

Neither the association with the hay nor the level of feeding significantly affected the digestibilities of the nutrients of the mangels.

The possibility cannot be excluded that at maximum levels of feedings the digestibility of the protein may be somewhat depressed.

Any possible depression of the digestibility of the dry matter, organic matter or nitrogen-free extract at maximum levels of feeding cannot be greater than 1 or 2%.

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APPENDIX

Table 11.—Calculation of coefficients of digestibility
(Collection period of 12 days, weights in kilogrammes. Coefficients in per cent.)

Animals	Original weights	Dry matter	Organic matter	Nitrogen	Ether extract	Crude fibre	N-free extract
			Period 1				
Animal A							
Hay	48.000	41.227	38.139	0.770	0.771	15.839	16.713
Mangels	60.000	6.324	5.703	0.135	0.032	0.525	4.300
Total ration	108.000	47.551	43.842	0.905	0.803	16.364	21.013
Feces	104.061	20.465	18.441	0.367	0.467	9.103	6.729
Digested		27.086	25.401	0.538	0.336	7.261	14.284
Coefficient		57.0	57.9	59.4	41.8	44.4	68.0
Dig. from hay		21.520	20.214	0.443	0.329	6.652	10.245
Dig. from mangels		5.566	5.187	0.095	0.007	0.609	4.039
Coeff. of mangels		88.0	91.0	70.4	21.9	116.0	93.9

TABLE 11.—CALCULATION OF COEFFICIENTS OF DIGESTIBILITY—*Continued*
(Collection period of 12 days. Weights in kilogrammes. Coefficients in per cent)—*Continued*

Animals	Original weights	Dry matter	Organic matter	Nitrogen	Ether extract	Crude fibre	N-free extract
			PERIOD 1—*Concluded*				
Animal B							
Hay	48.000	41.227	38.139	0.770	0.771	15.839	16.713
Mangels	120.000	12.648	11.406	0.271	0.065	1.050	8.599
Total ration	168.000	53.875	49.545	1.041	0.836	16.889	25.312
Feces	107.470	21.462	19.063	0.399	0.483	9.666	6.621
Digested		32.413	30.482	0.642	0.353	7.223	18.691
Coefficient		60.2	61.5	61.7	42.2	42.8	73.8
Dig. from hay		21.520	20.214	0.443	0.329	6.652	10.245
Dig. from mangels		10.893	10.268	0.199	0.024	0.571	8.446
Coeff. of mangels		86.1	90.0	73.4	36.9	54.4	98.2
Animal C							
Hay	48.000	41.227	38.139	0.770	0.771	15.839	16.713
Mangels	192.000	20.237	18.250	0.433	0.103	1.680	13.759
Total ration	240.000	61.464	56.389	1.203	0.874	17.519	30.472
Feces	127.063	22.307	19.927	0.433	0.509	9.648	7.241
Digested		39.157	36.462	0.770	0.365	7.871	23.231
Coefficient		63.7	64.7	64.0	41.8	44.9	76.2
Dig. from hay		21.520	20.214	0.443	0.329	6.652	10.245
Dig. from mangels		17.637	16.248	0.327	0.036	1.219	12.986
Coeff. of mangels		87.2	89.0	75.5	35.0	72.6	94.4
Animal D							
Hay	48.000	41.227	38.139	0.770	0.771	15.839	16.713
Mangels	264.000	27.826	25.093	0.596	0.142	2.310	18.919
Total ration	312.000	69.053	63.232	1.366	0.913	18.149	35.632
Feces	143.863	23.764	21.181	0.506	0.577	9.917	7.664
Digested		45.289	42.051	0.860	0.336	8.232	27.968
Coefficient		65.6	66.5	63.0	36.8	45.4	78.5
Dig. from hay		21.520	20.214	0.443	0.329	6.652	10.245
Fig. from mangels		23.769	21.837	0.417	0.007	1.580	17.723
Coeff. of mangels		85.4	87.0	70.0	4.9	68.4	93.7
			PERIOD 2				
*Animal A**							
Hay	64.000	55.187	50.595	1.155	1.049	20.149	22.180
Mangels	975.000	100.815	90.129	2.064	0.575	7.571	69.089
Total ration	1039.000	156.002	140.724	3.219	1.624	27.720	91.269
Feces	315.466	43.275	37.121	1.228	1.359	15.146	13.649
Digested		112.727	103.603	1.991	0.265	12.574	77.620
Coefficient		72.3	73.6	61.9	16.3	45.4	85.0
Dig. from hay		28.808	26.815	0.664	0.448	8.463	13.596
Dig. from mangels		83.919	76.788	1.327	—	4.111	64.024
Coeff. of mangels		83.2	85.2	64.3	—	54.3	92.7
Animal B							
Hay	90.000	77.607	71.150	1.624	1.475	28.334	31.190
Feces	182.882	37.205	33.503	0.672	0.956	16.061	12.579
Digested		40.402	37.647	0.952	0.519	12.273	18.611
Coefficient		52.1	52.9	58.6	35.2	43.3	59.7

* Collection period of 16 days.

TABLE 11.—CALCULATION OF COEFFICIENTS OF DIGESTIBILITY—*Continued*
(Collection period of 12 days. Weights in kilogrammes. Coefficients in per cent)—*Continued*

Animals	Original weights	Dry matter	Organic matter	Nitrogen	Ether extract	Crude fibre	N-free extract
			PERIOD 2—*Concluded*				
Animal C							
Mangels	336.000	34.742	31.059	0.711	0.198	2.609	23.809
Feces	31.623	5.188	4.170	0.148	0.195	1.944	1.186
Digested		29.554	26.889	0.563	0.003	0.665	22.623
Coefficient		85.1	86.6	79.2	1.5	25.5	95.0
Animal D							
Hay	48.000	41.390	37.946	0.866	0.786	15.111	16.635
Mangels	60.000	6.204	5.546	0.127	0.035	0.466	4.252
Total ration	108.000	47.594	43.492	0.993	0.821	15.577	20.887
Feces	112.460	21.139	18.966	0.391	0.539	9.083	6.993
Digested		26.455	24.526	0.602	0.282	6.494	13.894
Coefficient		55.6	56.4	60.6	34.3	41.7	66.5
Dig. from hay		21.606	20.111	0.498	0.336	6.347	10.197
Dig. from mangels		4.849	4.415	0.104	—	0.147	3.697
Coeff. of mangels		78.2	79.6	81.9	—	31.5	86.9
			PERIOD 3				
Animal A							
Hay	48.000	41.477	38.051	0.817	0.771	15.226	16.948
Mangels	120.000	11.796	10.481	0.269	0.108	1.000	7.690
Total ration	168.000	53.273	48.532	1.086	0.879	16.226	24.638
Feces	118.654	21.684	19.164	0.445	0.536	8.903	7.060
Digested		31.589	29.368	0.641	0.343	7.323	17.578
Coefficient		59.3	60.5	59.0	39.0	45.1	71.3
Dig. from hay		21.651	20.167	0.470	0.329	6.395	10.389
Dig. from mangels		9.938	9.201	0.171	0.014	0.928	7.189
Coeff. of mangels		84.2	87.8	63.6	13.0	92.8	93.5
Animal B							
Hay	48.000	41.477	38.051	0.817	0.771	15.226	16.948
Mangels	600.000	58.980	52.404	1.346	0.543	5.002	38.449
Total ration	648.000	100.457	90.455	2.163	1.314	20.228	55.397
Feces	195.342	29.874	25.378	0.792	0.822	10.626	9.425
Digested		70.583	65.077	1.371	0.492	9.602	45.972
Coefficient		70.3	71.9	63.4	37.4	47.5	83.0
Dig. from hay		21.651	20.167	0.470	0.329	6.395	10.389
Dig. from mangels		48.932	44.910	0.901	0.163	3.207	35.583
Coeff. of mangels		83.0	85.7	66.9	30.0	64.1	92.5
Animal C							
Hay	48.000	41.477	38.051	0.817	0.771	15.226	16.948
Mangels	264.000	25.951	23.057	0.592	0.239	2.201	16.917
Total ration	312.000	67.428	61.108	1.409	1.010	17.427	33.865
Feces	136.169	23.633	20.719	0.521	0.574	9.453	7.633
Digested		43.795	40.389	0.888	0.436	7.974	26.232
Coefficient		65.0	66.1	63.0	43.2	45.8	77.5
Dig. from hay		21.651	20.167	0.470	0.329	6.395	10.389
Dig. from mangels		22.144	20.222	0.418	0.107	1.579	15.843
Coeff. of mangels		85.3	87.7	70.6	44.8	71.7	93.7

TABLE 11.—CALCULATION OF COEFFICIENTS OF DIGESTIBILITY—*Continued*
(Collection period of 12 days. Weights in kilogrammes. Coefficients in per cent)—*Continued*

Animals	Original weights	Dry matter	Organic matter	Nitrogen	Ether extract	Crude fibre	N-free extract
			PERIOD 3—*Concluded*				
*Animal D**							
Hay	64.000	55.302	50.734	1.089	1.029	20.301	22.596
Mangels	835.000	82.081	72.929	1.873	0.755	6.960	53.509
Total ration	899.000	137.383	123.663	2.962	1.784	27.261	76.105
Feces	269.395	39.695	34.221	1.068	1.076	14.032	12.825
Digested		97.688	89.442	1.894	0.708	13.229	63.280
Coefficient		71.1	72.3	63.9	39.7	48.5	83.1
Dig. from hay		28.868	26.889	0.626	0.439	8.526	13.851
Dig. from mangels		68.820	62.553	1.268	0.269	4.703	49.429
Coeff. of mangels		83.8	85.8	67.7	35.6	67.6	92.4
			PERIOD 4				
Animal A							
Hay	90.000	77.985	71.933	1.538	1.435	29.806	31.077
Feces	200.240	37.430	33.908	0.645	0.805	16.978	12.168
Digested		40.555	38.025	0.893	0.630	12.828	18.909
Coefficient		52.0	52.9	58.1	43.9	43.0	60.8
Animal B							
Mangels	480.000	47.088	42.078	1.038	0.447	4.125	31.017
Feces	42.948	6.278	4.754	0.256	0.294	1.659	1.289
Digested		40.810	37.324	0.782	0.153	2.466	29.728
Coefficient		86.7	88.7	75.3	34.2	59.8	95.8
Animal C							
Hay	48.000	41.592	38.364	0.820	0.765	15.896	16.574
Mangels	420.000	41.202	36.818	0.908	0.391	3.609	27.140
Total ration	468.000	82.794	75.182	1.728	1.156	19.505	43.714
Feces	165.660	25.369	22.315	0.605	0.710	10.168	7.869
Digested		57.425	52.867	1.123	0.446	9.337	35.845
Coefficient		69.4	70.3	65.0	38.6	47.9	82.0
Dig. from hay		21.711	20.333	0.472	0.327	6.676	10.160
Dig. from mangels		35.714	32.534	0.651	0.119	2.661	25.685
Coeff. of mangels		86.7	88.4	71.7	30.4	73.7	94.6
Animal D							
Hay	48.000	41.592	38.364	0.820	0.765	15.896	16.574
Mangels	120.000	11.772	10.519	0.259	0.112	1.031	7.754
Total ration	168.000	53.364	48.883	1.079	0.877	16.927	24.328
Feces	128.536	21.936	19.832	0.419	0.537	9.805	7.033
Digested		31.428	29.051	0.660	0.340	7.122	17.295
Coefficient		58.9	59.4	61.2	38.8	42.1	71.1
Dig. from hay		21.711	20.333	0.472	0.327	6.676	10.160
Dig. from mangels		9.717	8.718	0.188	0.013	0.446	7.135
Coeff. of mangels		82.5	82.9	72.6	11.6	43.3	92.0
			PERIOD 5				
Animal A							
Hay	48.000	41.750	38.494	0.820	0.743	15.928	16.696
Mangels	600.000	57.900	51.792	1.277	0.452	4.684	38.677
Total ration	648.000	99.650	90.286	2.097	1.195	20.612	55.373
Feces	185.709	28.594	25.051	0.743	0.824	11.455	8.681
Digested		71.056	65.235	1.354	0.371	9.157	46.692
Coefficient		71.3	72.3	64.6	31.0	44.4	84.3
Dig. from hay		21.794	20.402	0.472	0.317	6.690	10.235
Dig. from mangels		49.262	44.833	0.882	0.054	2.467	36.457
Coeff. of mangels		85.1	86.6	69.1	11.9	52.7	94.3

* Collection period of 16 days.

TABLE 11.—CALCULATION OF COEFFICIENTS OF DIGESTIBILITY—*Continued*
(Collection period of 12 days. Weights in kilogrammes. Coefficients in per cent)—*Continued*

Animals	Original weights	Dry matter	Organic matter	Nitrogen	Ether extract	Crude fibre	N-Free extract
			PERIOD 5—*Concluded*				
Animal B							
Hay	48.000	41.750	38.494	0.820	0.743	15.928	16.696
Mangels	264.000	25.476	22.788	0.562	0.199	2.061	17.018
Total ration	312.000	67.226	61.282	1.382	0.942	17.989	33.714
Feces	117.691	23.560	21.041	0.492	0.629	10.062	7.436
Digested		43.666	40.241	0.890	0.313	7.927	26.278
Coefficient		65.0	65.7	64.4	33.2	44.1	77.9
Dig. from hay		21.794	20.402	0.472	0.317	6.690	10.235
Dig. from mangels		21.872	19.839	0.418	—	1.237	16.043
Coeff. of mangels		85.9	87.1	74.4	—	60.0	94.3
Animal C							
Hay	48.000	41.750	38.494	0.820	0.743	15.928	16.696
Mangels	650.000	62.725	56.108	1.383	0.489	5.074	41.900
Total ration	698.000	104.475	94.602	2.203	1.232	21.002	58.596
Feces	181.472	27.116	24.009	0.782	0.822	10.459	8.531
Digested		77.359	70.593	1.421	0.410	10.543	50.065
Coefficient		74.0	74.6	64.5	33.3	50.2	85.4
Dig. from hay		21.794	20.402	0.472	0.317	6.690	10.235
Dig. from mangels		55.565	50.191	0.949	0.093	3.853	39.830
Coeff. of mangels		88.6	89.5	68.6	19.0	75.9	95.1
Animal D							
Hay	90.000	78.282	72.176	1.538	1.393	29.865	31.305
Feces	223.126	38.029	34.584	0.647	0.920	17.680	12.184
Digested		40.253	37.592	0.891	0.473	12.185	19.121
Coefficient		51.4	52.1	57.9	34.0	40.8	61.1
			PERIOD 6				
Animal A							
Mangels	480.000	46.992	42.189	1.059	0.320	4.041	31.212
Feces	42.184	6.092	5.164	0.248	0.356	1.702	1.707
Digested		40.900	37.025	0.811	—	2.339	29.505
Coefficient		87.0	87.8	76.6	—	57.9	94.5
Animal B							
Hay	48.000	42.398	39.078	0.819	0.729	16.120	17.112
Mangels	420.000	41.118	36.916	0.927	0.280	3.536	27.311
Total ration	468.000	83.516	75.994	1.746	1.009	19.656	44.423
Feces	153.655	26.764	24.248	0.576	0.768	11.562	8.540
Digested		56.752	51.746	1.170	0.241	8.094	35.883
Coefficient		68.0	68.1	67.0	23.9	41.2	80.8
Dig. from hay		22.132	20.711	0.471	0.311	6.770	10.490
Dig. from mangels		34.620	31.035	0.699	—	1.324	25.393
Coeff. of mangels		84.2	84.1	75.4	—	37.4	93.0
Animal C							
Hay	48.000	42.398	39.078	0.819	0.729	16.120	17.112
Mangels	120.000	11.748	10.547	0.265	0.080	1.010	7.803
Total ration	168.000	54.146	49.625	1.084	0.809	17.130	24.915
Feces	124.121	22.886	20.689	0.416	0.570	10.324	7.216
Digested		31.260	28.936	0.668	0.239	6.806	17.699
Coefficient		57.7	58.3	61.6	29.5	39.7	71.0
Dig. from hay		22.132	20.711	0.471	0.311	6.770	10.490
Dig. from mangels		9.128	8.225	0.197	—	0.036	7.209
Coeff. of mangels		77.7	78.0	74.3	—	3.6	92.4

TABLE 11.—CALCULATION OF COEFFICIENTS OF DIGESTIBILITY—*Continued*
(Collection period of 12 days. Weights in kilogrammes. Coefficients in per cent)—*Continued*

Animals	Original weights	Dry matter	Organic matter	Nitrogen	Ether extract	Crude fibre	N-free extract
			PERIOD 6—*Concluded*				
Animal D							
Hay	48.000	42.398	39.078	0.819	0.729	16.120	17.112
Mangels	600.000	58.740	52.737	1.324	0.399	5.052	39.015
Total ration	648.000	101.138	91.815	2.143	1.128	21.172	56.127
Feces	203.876	29.439	26.336	0.751	0.992	11.596	9.447
Digested		71.699	65.479	1.392	0.136	9.576	46.680
Coefficient		70.9	71.3	65.0	12.1	45.2	83.2
Dig. from hay		22.132	20.711	0.471	0.311	6.770	10.490
Dig. from mangels		49.567	44.768	0.921	—	2.806	36.190
Coeff. of mangels		84.4	84.9	69.6	—	55.5	92.8
			PERIOD 7				
Animal C							
Hay	90.000	80.046	73.554	1.622	1.441	28.753	33.219
Feces	198.832	38.287	34.573	0.712	0.953	17.329	12.145
Digested		41.759	38.981	0.910	0.488	11.424	21.074
Coefficient		52.2	53.0	56.1	33.9	39.7	63.4
			PERIOD 8				
Animal A							
Hay	90.000	79.767	73.362	1.609	1.787	29.785	31.739
Feces	193.066	37.892	34.148	0.666	0.913	17.237	12.114
Digested		41.875	39.214	0.943	0.874	12.548	19.625
Coefficient		52.5	53.5	58.6	48.9	42.1	61.8
Animal B							
Hay	48.000	42.542	39.126	0.858	0.953	15.885	16.927
Mangels	192.000	21.331	18.778	0.463	0.111	1.928	13.844
Total ration	240.000	63.873	57.904	1.321	1.064	17.813	30.771
Feces	106.681	22.442	19.801	0.441	0.626	9.430	7.206
Digested		41.431	38.103	0.880	0.438	8.383	23.565
Coefficient		64.9	65.8	66.6	41.2	47.1	76.6
Dig. from hay		22.207	20.737	0.493	0.407	6.672	10.376
Dig. from mangels		19.224	17.366	0.387	0.031	1.711	13.189
Coeff. of mangels		90.1	92.5	83.6	27.9	88.7	95.3
Animal C							
Hay	48.000	42.542	39.126	0.858	0.953	15.885	16.927
Mangels	600.000	66.660	58.681	1.447	0.347	6.026	43.262
Total ration	648.000	109.202	97.807	2.305	1.300	21.911	60.189
Feces	212.385	32.367	27.664	0.912	0.948	11.536	10.053
Digested		76.835	70.143	1.393	0.352	10.375	50.136
Coefficient		70.4	71.7	60.4	27.1	47.4	83.3
Dig. from hay		22.207	20.737	0.493	0.407	6.672	10.376
Dig. from mangels		54.628	49.406	0.900	—	3.703	39.760
Coeff. of mangels		82.0	84.2	62.2	—	61.5	91.9
Animal D							
Mangels	480.000	53.328	46.945	1.158	0.277	4.821	34.610
Feces	40.446	6.945	5.183	0.250	0.373	1.847	1.620
Digested		46.383	41.762	0.908	—	2.974	32.990
Coefficient		87.0	89.0	78.4	—	61.7	95.3

TABLE 11.—CALCULATION OF COEFFICIENTS OF DIGESTIBILITY—*Continued*
(Collection period of 12 days. Weights in kilogrammes. Coefficients in per cent)—*Continued*

Animals	Original weights	Dry matter	Organic matter	Nitrogen	Ether extract	Crude fibre	N-free extract
			PERIOD 9				
Animal A							
Hay	48.000	42.542	39.126	0.858	0.953	15.885	16.927
Mangels	264.000	29.304	25.603	0.632	0.144	2.620	18.892
Total ration	312.000	71.846	64.729	1.490	1.097	18.505	35.819
Feces	125.873	23.866	21.021	0.535	0.616	10.076	7.262
Digested		47.980	43.708	0.955	0.481	8.429	28.557
Coefficient		66.8	67.5	64.1	43.8	45.5	79.7
Dig. from hay		22.207	20.737	0.493	0.407	6.672	10.376
Dig. from mangels		25.773	22.971	0.462	0.074	1.757	18.181
Coeff. of mangels		88.0	89.7	73.1	51.4	67.0	96.2
Animal B							
Hay	90.000	79.767	73.362	1.609	1.787	29.785	31.739
Feces	186.192	37.711	34.162	0.647	0.879	17.019	12.486
Digested		42.056	39.200	0.962	0.908	12.766	19.253
Coefficient		52.7	53.4	59.8	50.8	42.9	60.7
Animal C							
Mangels	480.000	53.280	46.551	1.148	0.261	4.763	34.350
Feces	52.807	8.515	6.729	0.310	0.399	2.540	2.076
Digested		44.765	39.822	0.838	—	2.223	32.274
Coefficient		84.0	85.5	73.0	—	46.7	94.0
Animal D							
Hay	48.000	42.542	39.126	0.858	0.953	15.885	16.927
Mangels	420.000	46.620	40.732	1.005	0.228	4.168	30.056
Total ration	468.000	89.162	79.858	1.863	1.181	20.053	46.983
Feces	161.771	25.119	21.994	0.604	0.691	10.115	7.794
Digested		64.043	57.864	1.259	0.490	9.938	39.189
Coefficient		71.8	72.5	67.6	41.5	49.6	83.4
Dig. from hay		22.207	20.737	0.493	0.407	6.672	10.376
Dig. from mangels		41.836	37.127	0.766	0.083	3.266	28.813
Coeff. of mangels		89.7	91.1	76.2	36.4	78.4	95.9
			PERIOD 10				
Animal A							
Mangels	480.000	52.080	46.028	1.160	0.271	4.781	33.727
Feces	46.768	6.702	5.387	0.311	0.412	1.669	1.578
Digested		45.378	40.641	0.849	—	3.112	32.149
Coefficient		87.1	88.3	73.2	—	65.1	95.3
Animal B							
Hay	48.000	42.101	38.830	0.841	0.922	15.573	17.080
Mangels	60.000	6.510	5.754	0.145	0.034	0.598	4.216
Total ration	108.000	48.611	44.584	0.986	0.956	16.171	21.296
Feces	84.949	20.463	18.470	0.368	0.520	9.210	6.509
Digested		28.148	26.114	0.618	0.436	6.961	14.787
Coefficient		57.9	58.6	62.7	45.6	43.0	69.4
Dig. from hay		21.977	20.580	0.484	0.394	6.541	10.470
Dig. from mangels		6.171	5.534	0.134	0.042	0.420	4.317
Coeff. of mangels		94.8	96.2	92.4	—	70.2	102.4

TABLE 11.—CALCULATION OF COEFFICIENTS OF DIGESTIBILITY—*Continued*
(Collection period of 12 days. Weights in kilogrammes. Coefficients in per cent)—*Continued*

Animals	Original weights	Dry matter	Organic matter	Nitrogen	Ether extract	Crude fibre	N-free extract
			PERIOD 10—*Concluded*				
Animal C							
Hay	90.000	78.939	72.805	1.576	1.729	29.200	32.026
Refused hay	3.646	3.184	2.935	0.058	0.057	1.243	1.271
Consumed	86.354	75.755	69.870	1.518	1.672	27.957	30.755
Feces	196.788	35.635	32.460	0.683	0.827	16.157	11.517
Digested		40.120	37.410	0.835	0.845	11.800	19.238
Coefficient		53.0	53.5	55.0	50.5	42.2	62.6
Animal D							
Hay	48.000	42.101	38.830	0.841	0.922	15.573	17.080
Mangels	192.000	20.832	18.411	0.464	0.108	1.912	13.491
Total ration	240.000	62.933	57.241	1.305	1.030	17.485	30.571
Feces	140.040	23.648	21.080	0.526	0.608	10.211	7.255
Digested		39.285	36.161	0.779	0.422	7.274	23.316
Coefficient		62.4	63.2	59.7	41.0	41.6	76.3
Dig. from hay		21.977	20.580	0.484	0.394	6.541	10.470
Dig. from mangels		17.308	15.581	0.295	0.028	0.733	12.846
Coeff. of mangels		83.1	84.6	63.6	25.9	38.3	95.2
			PERIOD 11				
Animal A							
Hay	48.000	42.101	38.830	0.841	0.922	15.573	17.080
Mangels	192.000	21.024	19.094	0.407	0.107	1.528	14.914
Total ration	240.000	63.125	57.924	1.248	1.029	17.101	31.994
Feces	119.297	23.238	20.656	0.513	0.892	9.109	7.615
Digested		39.887	37.268	0.735	0.137	7.992	24.379
Coefficient		63.2	64.3	58.9	13.3	46.7	76.2
Dig. from hay		21.977	20.580	0.484	0.394	6.541	10.470
Dig. from mangels		17.910	16.688	0.251	—	1.451	13.909
Coeff. of mangels		85.2	87.4	61.7	—	95.0	93.3
Animal B							
Hay	48.000	42.101	38.830	0.841	0.922	15.573	17.080
Mangels	700.000	76.650	69.614	1.484	0.391	5.572	54.376
Total ration	748.000	118.751	108.444	2.325	1.313	21.145	71.456
Feces	225.398	32.963	28.276	0.939	1.048	11.188	10.736
Digested		85.788	80.168	1.386	0.265	9.957	60.720
Coefficient		72.2	73.9	59.6	20.2	47.1	85.0
Dig. from hay		21.977	20.580	0.484	0.394	6.541	10.470
Dig. from mangels		63.811	59.588	0.902	—	3.416	50.250
Coeff. of mangels		83.2	85.6	60.8	—	61.3	92.4
Animal C							
Hay	48.000	42.101	38.830	0.841	0.922	15.573	17.080
Mangels	60.000	6.570	5.967	0.127	0.034	0.478	4.661
Total ration	108.000	48.671	44.797	0.968	0.956	16.051	21.741
Feces	98.189	21.249	19.096	0.399	0.574	9.333	6.838
Digested		27.422	25.701	0.569	0.382	6.718	14.903
Coefficient		56.3	57.4	58.8	40.0	41.9	68.5
Dig. from hay		21.977	20.580	0.484	0.394	6.541	10.470
Dig. from mangels		5.445	5.121	0.085	—	0.177	4.433
Coeff. of mangels		82.9	85.8	66.9	—	37.0	95.1

TABLE 11.—CALCULATION OF COEFFICIENTS OF DIGESTIBILITY—*Concluded*
(Collection period of 12 days. Weights in kilogrammes. Coefficients in per cent)—*Concluded*

Animals	Original weights	Dry matter	Organic matter	Nitrogen	Ether extract	Crude fibre	N-Free extract
			PERIOD 11—*Concluded*				
Animal D							
Hay	90.000	78.939	72.805	1.576	1.729	29.200	32.026
Feces	206.341	38.157	34.551	0.701	0.962	16.930	12.603
Digested		40.782	38.254	0.875	0.767	12.270	19.423
Coefficient		51.7	52.5	55.5	44.4	42.0	60.6
			PERIOD 12				
Animal A							
Hay	48.000	42.101	38.830	0.841	0.922	15.573	17.080
Mangels	420.000	45.444	41.204	0.868	0.427	3.304	32.043
Total ration	468.000	87.545	80.034	1.709	1.349	18.877	49.123
Feces	151.351	25.746	22.358	0.658	0.832	9.971	7.927
Digested		61.799	57.676	1.051	0.517	8.906	41.196
Coefficient		70.6	72.1	61.5	38.3	47.2	83.9
Dig. from hay		21.977	20.580	0.484	0.394	6.541	10.470
Dig. from mangels		39.822	37.096	0.567	0.123	2.365	30.726
Coeff. of mangels		87.6	90.0	65.3	28.8	71.6	95.9
Animal B							
Mangels	480.000	51.936	47.090	0.992	0.488	3.776	36.620
Feces	45.946	6.616	5.011	0.276	0.419	1.424	1.636
Digested		45.320	42.079	0.716	0.069	2.352	34.984
Coefficient		87.3	89.4	72.2	14.1	62.3	95.5
Animal D							
Mangels	480.000	51.936	47.090	0.992	0.488	3.776	36.620
Feces	60.199	8.132	6.322	0.340	0.413	1.936	2.114
Digested		43.804	40.768	0.652	0.075	1.840	34.506
Coefficient		84.3	86.6	65.7	15.4	48.7	94.2

PASTURE STUDIES XIII

THE UTILIZATION OF NATIVE AND APPLIED PHOSPHORUS BY PASTURE CROPS[1]

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INTRODUCTORY STATEMENT

The fertilizer trial plots of the Macdonald College pasture committee were located in the Eastern Townships of Quebec, in the neighbourhood of the town of Cowansville, throughout the seasons of 1931 to 1934 inclusive. The normal soil in this district is of the type described by McKibbin and Pugsley (6) as brown forest soil. A rough reconnaissance survey has indicated that soils of this type are mainly restricted to a narrow zone lying between the alluvial soils of the St. Lawrence valley and the upland podsol soils of the Appalachian region. Raymond (10) presented a sketch map showing the result of this survey.

The brown forest soils have not been intensively studied, but it may be stated that they are not as drastically leached as are the podsol soils, which are so important from the standpoint of area in Quebec province. In the virgin brown forest soil profile there is little tendency for peaty organic matter to accumulate at the surface, and well decomposed organic matter is distributed through the profile to considerable depth, decreasing gradually from the surface downward. Sesquioxides do not appear to have been translocated to any marked extent. The profile is devoid of any sharp division into layers, and there is no notable development of structure. These soils are distinctly acid, having a pH range of 5.0 to 6.0; they are in general not as acid as the upland podsol soils, and their lime requirement is lower. Genetically, these soils appear to have developed from parent material richer in basic elements than that which underlies the upland podsols, and under a forest cover that was made up mainly of deciduous species. Agriculturally they are somewhat superior to the podsols.

Several publications of the Macdonald College pasture committee deal with the various effects of top-dressing permanent pastures on the brown forest soil type with different fertilizers and amendments. Nowasad (8) reported the effects of fertilization on botanical composition and yield. Crampton and Finlayson (2) showed that the nutritive value of herbage clipped from fertilized areas was greater than that from the natural pasture. Dore (3) presented a detailed analysis of the succession and variation in botanical composition resulting from fertilizer application. The unpublished work of Stobbe (11) records the influence of fertilizer treatments on the contents of nitrogen, calcium, and phosphorus in the clipped herbage. All these workers have concluded that phosphorus, applied to the surface as superphosphate, is outstanding in producing beneficial results.

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[1] Contribution from the Macdonald College Pasture Committee, Professor L. C. Raymond, Chairman. Macdonald College Journal Series No. 97. Constructed from a Ph.D. thesis presented to McGill University by C. L. Wrenshall.

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This paper presents results obtained in a chemical study of the soil phosphorus conditions in field and greenhouse experiments, and traces the relation of these conditions to observed plant response. This work has already been cited by Raymond (10), and an abstract which summarized the results appeared in this journal (13). In view of their value in explaining the action of phosphorus in pasture fertilization, and as a contribution to the general study of soil phosphorus relationships, the data appear worthy of more detailed presentation.

A. PHOSPHORUS CONDITIONS IN THE SOIL OF THE PASTURE PLOTS

Experimental Material and Method

A total of 126 soil samples was obtained from the fertilizer trial plots. Various treatments had been laid down on several farms in each of four successive years. The sampling was done in September, 1934, so that the samples represented conditions existing at four different intervals of time after the addition of fertilizer. The treatments sampled were nil, superphosphate, and superphosphate plus muriate of potash; various rates of application were represented. The treatments had been applied as top-dressings broadcast on the surface of the pastures, with no attempt to work in the applications. Three samples, representing the soil layers (i) 0″ to ½″, (ii) ½″ to 1½″, (iii) 1½″ to 3″, were obtained from each plot studied.

The samples were air-dried, pulverized with a rubber pestle, and screened through a sieve of 20 meshes to the inch. All samples were analyzed for readily soluble phosphorus using the Quebec extraction method[4], the development of which was described in a previous publication (14). A few total-phosphorus determinations were made, using the standard A.O.A.C. magnesium nitrate fusion method.

Data and Discussion

Results of the analyses for readily soluble inorganic phosphorus are recorded in Table 1. Several points of considerable interest are revealed by these data.

Considering untreated soils, the soluble phosphorus is seen to be higher in the topmost one-half inch than in the succeeding layers. This is true in each case represented. Analyses for total phosphorus in samples from the 1934 series on farm No. 1 are presented in Table 2, and show a similar relationship for the distribution of total phosphorus. This situation is noteworthy, as it indicates that the plants act as pumps, bringing up some phosphorus from the lower soil layers, and, in returning to the soil, adding it to the upper layers where it is closely retained, a small portion in readily soluble inorganic form.

Surface application of superphosphate has resulted in an increase in the readily soluble phosphorus of the surface half-inch layer of soil. This is best observed in the data for the 1933 and 1934 treatments, where the

[4] The Quebec extracting solution contains 500 parts per million of calcium (Ca) and 1,270 parts per million of sulphate (SO_4), and has a reaction value of pH 3.0. It is prepared by dissolving 1.25 grams of pure calcium carbonate in the equivalent of 265 cc. of tenth-normal sulphuric acid for each litre of final solution. Two grams of soil are extracted with 400 cc. of Quebec solution for half an hour in an end-over-end shaker; filtration is immediately carried out, using high grade filter paper and suction, and phosphorus in the extract is determined colorimetrically following the Truog and Meyer (12) technique.

effect is sufficiently recent to be quite marked. The most pronounced result, together with total phosphorus data, is quoted in Table 2. It appears that all the phosphorus of the application has been retained by the surface half-inch layer, and the data throughout indicate that the effect of phosphorus additions has been confined to this thin stratum. Such a result betokens the great power of these soils to fix phosphate, and indicates that the reaction between soil and dissolved phosphate must be practically instantaneous.

The great power of most soils to fix additions of soluble phosphate is well known and has been noted by many authors. Evidently Quebec soils present no exception to the general rule. Midgley (7), in studies relative to phosphate fertilization of permanent pastures in Wisconsin, observed that a three-quarter inch layer of soil on a Buchner funnel completely retained the phosphorus of experimental applications of superphosphate. Brown and Munsell (1) found that superphosphate was almost altogether fixed in the surface inch of top-dressed pasture soil. It is believed, however, that these results are the first to demonstrate clearly that the effect of top-dressing with superphosphate may be entirely confined to the surface one-half inch of soil under field conditions.

It would be of interest in this connection to know what influence this lack of penetration of the applied phosphorus has upon its availability to plants. That it is available to a considerable extent is obvious from the practical results. Would the application be more effective if it were mingled with the soil to a greater depth? Would the effect on botanical composition be the same? Unfortunately we cannot as yet give direct answers to these questions. Midgley (7) found that the yield increase of blue-grass was much greater when the treatment was incorporated to a depth of three inches. On the other hand, practical instances in which top-dressing was superior to incorporation are known (5). Goedewaagen (4) showed a given amount of applied phosphorus to be more effective when mingled with only the surface zone than when incorporated throughout the soil of the culture. It is to be kept in mind that only a portion of the total phosphorus applied remains in a readily soluble condition (see Table 2). the remainder being fixed in relatively insoluble forms. With a greater ratio of soil to phosphorus, such as would occur if the treatment were worked in, a greater proportion might be fixed in difficultly soluble form. Probably there is an optimum condition between the extremes of positional unavailability and excessive dilution of the applied phosphate.

From Dore's results (3), it is evident that the grass species do not make a strong response to the applied phosphate in the first season after treatment, while white clover increases very markedly. Dore's comments on this point are instructive. By its habit of growth, white clover appears to be peculiarly adapted for obtaining nutrients in the uppermost part of the soil. The stolons of this species lie close to the surface of the ground and send down slender, white feeding roots directly into the topsoil. The grasses appear to have relatively few feeding roots in the surface half-inch layer, and, although they may be capable of responding to phosphate to as great an extent as is clover[5], such response is delayed and curtailed by the small ability of their root systems to come into contact with the supply.

[5] Cf. response of timothy and clover in the pot-culture experiment.

TABLE 1.—READILY SOLUBLE INORGANIC PHOSPHORUS IN SOIL. SAMPLES FROM THE PASTURE PLOTS AT SEPTEMBER, 1934

Year of fertilization	Soil from farm No.	Top dressing*	Parts per million of inorganic phosphorus dissolved by Quebec extraction		
			From soil horizon		
			0″ – ½″	½″ – 1½″	1½″ – 3″
1931	I	Nil	12	4	3
		5P	24	6	4
		5P, 1.6K	12	6	4
	II	Nil	9	5	4
		5P	13	5	3
		5P, 1.6K	10	5	4
1932	III	Nil	6	4	4
		5P	12	4	4
		5P, 1.6K	6	3	3
	I	Nil	12	7	5
		3P, 1.5K	13	7	6
		5P, 1.5K	15	7	6
		7P, 1.5K	17	7	5
	II	Nil	10	4	3
		3P, 1.5K	11	5	4
		5P, 1.5K	12	4	3
		7P, 1.5K	11	5	4
1933	I	Nil	10	5	3
		5P	23	5	4
		5P, 1.6K	30	9	6
	III	Nil	10	4	4
		5P	33	5	4
		5P, 1.6K	25	5	4
	IV	Nil	9	4	3
		5P	19	5	4
		5P, 1.6K	17	5	4
	II	Nil	12	5	4
		5P	47	8	4
		5P, 1.5K	26	5	3
1934	I	Nil	12	8	7
		7P	80	8	7
		7P, 2K	55	10	7
	III	Nil	9	5	4
		7P	53	5	4
		7P, 2K	33	7	4
	IV	Nil	7	3	2
		3P	12	3	3
		5P	24	4	3
		7P	34	3	2
		3P, 2K	22	3	2
		5P, 2K	40	5	4
		7P, 2K	35	3	3

* Fertilizer applications are designated in abbreviated form: P = superphosphate, K = muriate of potash; the numbers indicate the rate of application in hundreds of pounds per acre. Thus 5P = 500 lbs. of superphosphate per acre; 5P, 1.6K = 500 lbs. of superphosphate + 160 lbs. of muriate of potash per acre.

TABLE 2.—DISTRIBUTION OF PHOSPHORUS IN PASTURE SOIL FROM FARM I, 1934 SERIES

Depth of soil layer (inches)	Parts per million of phosphorus in soil			
	Unfertilized		Fertilized (7P)	
	Total	Readily soluble	Total	Readily soluble
0 – ½	1000	12	1200	80
½ – 1½	850	8	880	8
1½ – 3	700	7	700	7

Thus the concentration of added phosphate in a thin surface layer is undoubtedly a factor of paramount importance in determining the observed differential response of the sward species.

Where muriate of potash was added together with superphosphate in the original treatment, the amount of readily soluble phosphorus remaining in the soil at the time of sampling was generally lower than where superphosphate was added alone. This is true in 8 out of 13 comparable pairs. In these 13 cases the average soluble phosphorus in the surface of plots treated with phosphate alone was 31 parts per million, and the average for plots treated with both phosphate and potash was 26 parts per million. Furthermore, the values for farms I and II treated in 1932, where all treatments were of both elements and no direct comparison with phosphorus alone is possible, appear relatively low.

Generally, application of potash results in a significant yield increase, as shown by Nowosad (8). Thus the observed effect of potash on the soluble phosphorus status is attributable to increased consumption of phosphorus by the growing plants. It may also be due to increased reversion to difficultly soluble form, as appears to be the case in the pot culture experiment described in a later section.

The amount of easily soluble phosphorus remaining in the soil appears to diminish in a regular manner as the time since the application of fertilizer increases. This is to be expected if the plants are feeding on this particular fraction of the soil phosphorus. It might also be occasioned by a slow reversion to less soluble forms. Average values calculated for intervals of one crop season are presented in Table 3. Each average is calculated from all the values from plots which were fertilized in a given year, and the average of the nil plots is obtained from all available figures. The only average which is seriously out of line with the general trend is that for the

TABLE 3.—DEPLETION OF READILY SOLUBLE PHOSPHORUS AS RELATED TO BOTANICAL COMPOSITION AND YIELD

Number of crops removed since fertilization	Average soluble phosphorus—p.p.m. surface soil	Per cent ground covered by clover (Dore)	Per cent yield increase over untreated
1	39	40.2	51.4
2	27	30.5	34.0
3	12	18.3	18.3
4	15	14.8	–
Not fertilized	10	11.1	0.0

plots fertilized in 1932. In this case 7 of the 8 values included in the average are for plots treated with phosphate plus potash. If the observation made above concerning the effect of potash is sound, this average would be expected to be abnormally low, as it is.

It is well known that in the first season after fertilization the clover population of the sward is greatly increased and then suffers a gradual decline in the subsequent seasons. Dore (3) has presented such results obtained from the study of a series of plots through four successive seasons, and the several other series of plots have all shown similar trends, so that his data may be considered representative. The third column of Table 3 is calculated from Dore's data. The clover on untreated plots is the average for the four years; the other figures are average values for P and PK plots in each of the four years after fertilization. The close correspondence between the soluble phosphorus figures and those for ground covered by clover, expressed as they are in unrelated units, is doubtless fortuitous, but the high degree of correlation between these figures is unmistakable. It appears that the proportion of clover in the sward is very directly related to the amount of easily soluble phosphorus present in the top layer at the same time. That this is the case was strongly confirmed by refertilization experiments in which the treatment of plots originally fertilized in 1931 was repeated in the spring of 1935. On the P and PK treatments the clover responded strongly, just as it did after the original dressings. This occurred in spite of the fact that there was a closer sward of useful grass species at the time of the second application than at the first. This would seem to indicate that the proportion of white clover in the sward was directly conditioned by the amount of soluble phosphate; it increased sharply when the soluble phosphate was increased, decreased gradually as the phosphate slowly disappeared, and once more increased sharply when the soluble phosphate was suddenly replenished. There is very little support in this for the contention of Dore (3) that "The white clover declines, or better, is forced to decline due to the demands exerted on its territory by the slower growing, but stronger growing, grasses." Perhaps it would be better to state that the power of clover to compete depends directly on the supply of phosphorus available to it.

The fourth column of Table 3 shows data for the average percentage yield increase on P and PK plots in the years following fertilization. These figures are for the plots treated in 1933, and are known to be representative of the general behavior. Again, there is evident a direct relationship between the degree of yield response and the amount of soluble phosphate remaining in the soil.

B. THE POT CULTURE EXPERIMENT

A pot culture experiment was conducted in the greenhouse with a view to the further testing, under controlled conditions, of the soil and plant phosphorus relationships, and the extent to which these can be traced by soil analysis. Brown forest soil from a pasture in the Cowansville district was used, and the plants grown were timothy and wild white clover. Pasture conditions were imitated, in that the treatments applied were confined to the surface two-inch layer of soil, and that the plants were kept in the vegetative state by clipping at intervals. The experiment was

designed to avoid uncontrollable variation in material (soil and plants) and to be suitable for statistical analysis. The following treatments, each replicated three times with timothy and three times with clover, were tested:

Treatment	*Abbreviation*
1. Nil	Nil
2. 300 lbs. superphosphate (P) per acre	3P
3. 700 lbs. P per acre	7P
4. 1 ton limestone (L) per acre	L
5. 1 ton L + 300 lbs. P per acre	L, 3P
6. 1 ton L + 700 lbs. P per acre	L, 7P
7. 150 lbs. sulphur (S) per acre	S
8. 150 lbs. S + 300 lbs. P per acre	S, 3P
9. 150 lbs. S + 700 lbs. P per acre	S, 7P
10. 100 lbs. muriate of potash (K) per acre	K
11. 100 lbs. K + 300 lbs. P per acre	K, 3P
12. 100 lbs. K + 700 lbs. P per acre	K, 7P

Three clippings of clover and four of timothy were made in the course of the experiment. Each clipped sample was retained separately, oven dried, and weighed for yield of dry matter. Phosphorus was determined in each separate clipped sample by applying the colorimetric method of Truog and Meyer (12) to solutions of the plant ash. The data for yield and for phosphorus removal were subjected to statistical analysis of variance.

Soil samples representing the treated layer of soil were taken from the individual pots at the beginning and at the end of the experiment, and were analyzed for readily soluble phosphorus by the Quebec extraction method. Determinations of pH values were made on composites of the soil samples from each treatment.

Data and Discussion

The complete data from the experiment are too extensive and cumbersome to be reproduced here. The following is a summary of the information obtained by statistical examination of the results:

1. The yield of herbage and the phosphorus removed in the clipped herbage were significantly increased by phosphate fertilization at both rates, and the increases on the 7P treatments were significantly greater than those on the 3P treatments.

2. Application of lime caused a significant depression of both yield and phosphorus uptake in the case of timothy, but not in the case of clover. The effect of lime on clover was apparently parallel to that on timothy, but just failed to reach the 5% point of statistical significance.

3. Treatment with sulphur caused significant increases in both yield and phosphorus uptake of both species.

4. Treatment with potassium was without apparent effect on the growth of the plants.

5. There was no significant interaction between phosphate fertilization and the other treatments.

Tables 4 and 5 are designed to reveal the statistically significant differences in yield and phosphorus removal. The data in Table 4, showing effects of the treatments on total yield, are also given expression in Figure 1. The increases due to phosphate addition at two different rates are apparent; so also are the decreases due to lime, and the increases due to sulphur.

The depressions of yield and phosphorus removal caused by lime, and the increases due to sulphur tend to be uniform, and therefore are not related to the phosphate application, but are direct effects on the soil.

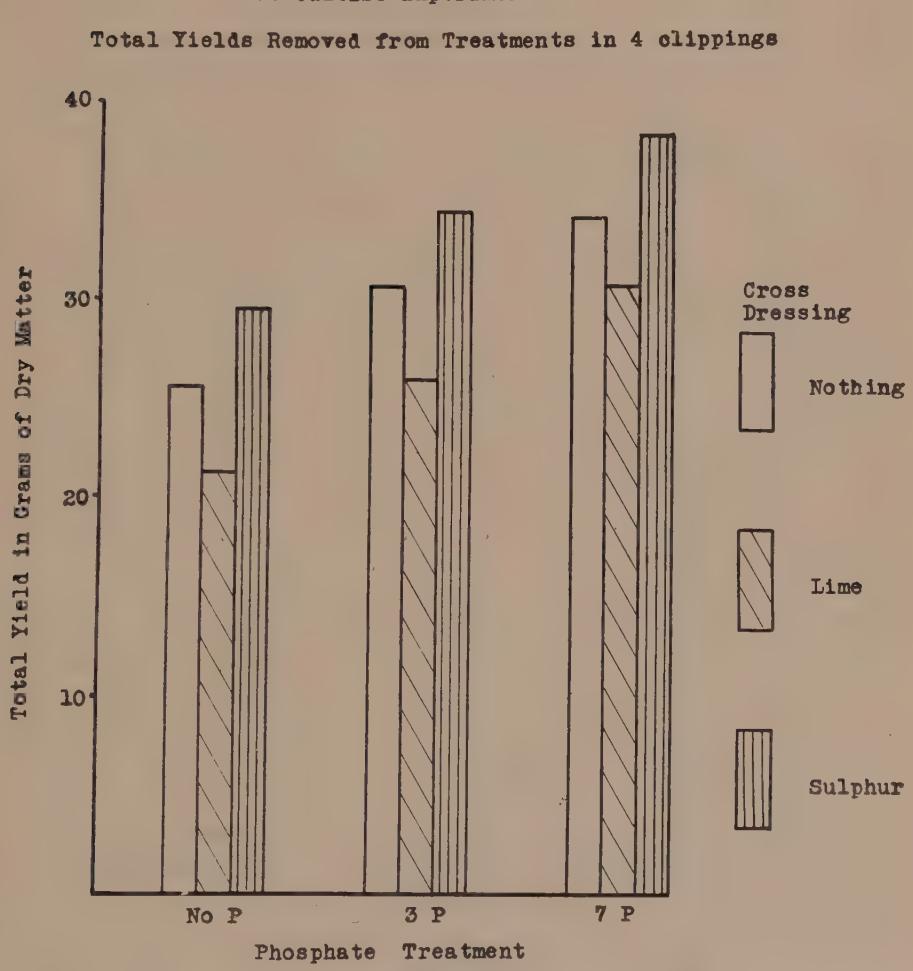

FIGURE 1

The nature of these effects is at present uncertain. We have previously shown (14) that the solubility of soil phosphate is depressed by the presence of calcium in the acid extracting solution, and postulated that a similar effect is operative in the soil. Thus an increase in calcium saturation of the soil, produced by liming, might be expected to reduce the solubility

of phosphate, and a decrease in calcium saturation, brought about by the oxidation of sulphur to sulphuric acid, should increase phosphate solubility. Pierre and Browning (9) obtained striking results showing bad effects from liming, and traced these effects to a decrease in the solubility of soil phosphate. That these factors are in operation here would seem to offer a plausible explanation of the observed results, except that there is no inter-action between the phosphate treatments and the cross-treatments of sulphur and lime, such as would be predicted on the basis of the assumption. The action of sulphur and lime may be due to other effects not directly related to the phosphorus nutrition of the plants.

TABLE 4.—TOTAL YIELDS OF DRY MATTER CLIPPED FROM DIFFERENT TREATMENTS (GRAMS)

Phosphatic treatments	Cross dressings		
	None	Lime	Sulphur
None	25.7	21.5	29.8
3P	30.6	26.1	34.6
7P	34.1	30.9	38.5

The results of this pot culture experiment with respect to sulphur and lime appear to be somewhat at variance with general agricultural belief, and the application of sulphur to acid soils is hardly to be recommended on such evidence. It is to be kept in mind that the result obtained is for one season's growth on a single sample of soil, and with plant species which appear to be well adapted to acid conditions. On the other hand, the pasture experimentation on this soil type has failed to show any clear-cut beneficial effect of lime applied as a surface dressing. In some cases slight yield increases have been recorded, but in other instances slight yield depressions. Likewise, in the case of potash, the absence of a significant yield response in this instance is not surprising; potash is often, but not always, beneficial. The degree of response to phosphate in the pot tests is of the same order as that observed in field trials. Altogether, the results are in accord with field observations.

TABLE 5.—PHOSPHORUS REMOVED IN THE CLIPPINGS FROM DIFFERENT TREATMENTS (MILLIGRAMS)

Phosphatic treatments	Cross dressings		
	None	Lime	Sulphur
None	76.9	68.7	95.8
3P	94.6	85.3	111.2
7P	122.1	103.0	133.2

The data for chemical determinations made on soil samples from the pots are recorded in Table 6. From the pH values it is evident that the addition of calcium carbonate has had an appreciable effect, increasing the pH values by approximately one unit. The addition of sulphur has not produced a marked effect, but the values are evidently reduced by 0.1 to 0.2 units. The treatments with superphosphate and muriate of potash have not caused any consistent effect on the soil reaction. The data for soluble phosphorus before growth show that the phosphate treatments have resulted in marked increases, while the other treatments have been without apparent effect. The increases in soluble soil phosphorus caused by phosphate application are evidently related to the increases in yield and phosphorus removal. The figures for available phosphate after growth

are, in general, lower than those obtained initially, indicating that some of this phosphorus has been removed or converted into less soluble forms.

TABLE 6.—CHEMICAL DATA ON SOIL FROM THE POTS

Treatment	Time of sampling relative to growth	Soluble phosphorus—p.p.m. of soil						pH of soil
		Replications						
		Clover			Timothy			
		1	2	3	4	5	6	
Nil	Before	7	6	6	7	7	7	
	After	*			6	6	7	5.60
3P	Before	18	19	17	16	18	19	
	After				10	11	14	5.58
7P	Before	23	25	22	27	25	34	
	After				17	15	21	5.57
L	Before	7	7	7	7	7	7	
	After				9	8	8	6.62
L, 3P	Before	15	18	16	16	18	18	
	After				13	16	14	6.62
L, 7P	Before	33	25	32	28	30	32	
	After				20	16	18	6.75
S	Before	7	7	7	7	7	7	
	After				4	3	4	5.35
S, 3P	Before	15	13	14	16	14	16	
	After				9	5	8	5.43
S, 7P	Before	25	28	24	29	24	29	
	After				16	13	16	5.49
K	Before	6	7	7	7	7	8	
	After				2	2	3	5.51
K, 3P	Before	13	15	17	18	15	15	
	After				10	9	8	5.56
K, 7P	Before	30	32	32	30	31	31	
	After				18	13	16	5.55

* Unfortunately, through not properly anticipating the value of these results, soil samples were not taken from the pots bearing clover at the conclusion of the growth period.

Several samples of the untreated subsurface soil were examined before and after the growth of plants. In no case was there a detectable decrease in the readily soluble phosphate of the lower, untreated layers. Hence we may confine our attention to the changes in phosphate status occurring in the treated zone. When the amount of soil involved in the change is known, the data of Table 6 permit the calculation of the apparent amount of soluble phosphorus that has passed from the soil to the timothy plants, assuming that the entire decrease is due to removal by the crop. This has been done, and the results are shown in Table 7, where they are compared with the actual amounts of phosphorus that were removed in the clippings.

The data of Table 7 are of considerable interest and significance. The phosphorus removed by growing plants is in all cases considerably more than is indicated by the disappearance of soluble phosphate. Evidently the soil is supplying the plants with phosphorus in a manner that is not detected by the acid extraction method. In the case of untreated soil the change in soluble phosphate is insignificant while the plants have obtained 44.3 milligrams of phosphorus. On the lime treatment the soluble phosphate appears to have increased slightly, while the amount obtained by the plants decreased to 35.7 milligrams. Where sulphur was applied the soluble phosphorus decreased sufficiently to account for the extra phosphorus obtained by the plants on this treatment, but the bulk of the phosphorus taken up is not accounted for. The result with potassium is anomalous, for the soluble phosphorus has decreased considerably without a corresponding increase in the amount taken up by the plants. In no case has the decrease in acid extractable[6] phosphorus accounted for

TABLE 7.—COMPARISON OF PHOSPHORUS REMOVAL FROM SOIL AS SHOWN BY CHEMICAL TESTS ON THE SOIL AND BY ANALYSIS OF TIMOTHY CLIPPINGS

Treatment	Apparent P removal shown by soil tests	Actual P removal in clipped timothy	Difference
	mgms.	mgms.	mgms.
Nil	2.7	44.3	41.6
3P	23.	55.1	31.2
7P	43.7	69.6	25.9
L	−5.3	35.7	41.0
L, 3P	11.9	47.3	35.4
L, 7P	47.7	56.9	9.2
S	13.3	54.6	41.3
S, 3P	31.8	61.5	29.7
K	19.9	48.2	18.3
K, 3P	27.8	56.5	28.5
K, 7P	59.6	70.7	11.1

the total phosphorus uptake by the crop, even though it may be safely assumed that part of the decrease was due to reversion to less soluble forms.

The general purpose of acid extraction methods is to determine the need of soils for phosphate fertilization, and the fundamental assumption is that the phosphorus soluble in the extracting solution is the store of phosphorus which is most readily available to plants. If this assumption is correct it is to be expected that the store of readily soluble phosphorus

[6] Acid extraction methods other than the Quebec extraction show the same differences in soluble phosphorus before and after the growth of plants, and hence fail in the same way to account for the phosphorus removed.

would diminish as phosphorus is removed by the plants. The data presented here show that this is not necessarily so. In no instance is the decrease in soluble phosphorus sufficient to account for the total removal by the plants; furthermore, the store of readily soluble phosphorus may remain constant or even increase while the plants are removing substantial amounts of phosphorus. However one may choose to interpret these data, it is ultimately some form of phosphorus other than that determined by dilute acid extraction that is supplying most of the phosphorus obtained by the plant.

To understand the behavior of the easily soluble phosphate one must bear in mind at all times that, although soluble in the dilute acid extractant, it is not in solution in the soil, but exists in an undissolved state. This particular fraction of undissolved phosphate will be in equilibrium with the soil solution under a certain set of conditions when it will tend neither to increase nor to decrease; such conditions were evidently approximated in the untreated soil during the pot culture experiment. Under another set of conditions the soil solution will be unsaturated with respect to the easily soluble phosphorus, when the latter will continuously pass into solution, fulfilling the tendency to restore equilibrium. Such conditions evidently exist when superphosphate has been added to the soil and a quantity of easily soluble phosphate formed which is not in equilibrium with the soil system, or when the environment of the native readily soluble phosphorus is changed, for example by addition of sulphur. From this point of view, soil phosphate should be regarded as available when it is actively in process of disappearing from the soil. Finally, conditions may be such that the solubility product of some readily soluble phosphate compound is exceeded in the soil solution, and an increase in the undissolved quantity of readily soluble phosphate will ensue so long as these conditions persist. In the experiment cited, such conditions were evidently brought about by the addition of calcium carbonate to the soil.

The same argument will, in its general application, embrace all the forms of inorganic phosphate that may be considered as existing in solubility equilibrium with the soil solution, and hence will apply indifferently to any method of acid extraction that may be proposed. Whence, then, in the experiment under consideration, did the phosphorus taken up by the plants arise?

We have recently shown (15) that a considerable part of the phosphorus of these soils exists in organic form as nucleotides. This finding provides a real basis for the belief that the cycle of phosphorus in the soil is similar in certain respects to that of nitrogen. In the case of nitrogen there exists an accumulation of relatively stable and inert forms which, in the course of a biological cycle, give rise to inorganic nitrogen compounds. These compounds may be utilized by plants, may be lost from the soil by leaching or by denitrification, or may again be built up into complex organic compounds by biological activity within the soil. Similarly, the breakdown of organic phosphorus molecules would give rise to phosphoric acid which, entering the soil solution, may be utilized by higher plants, or may react with basic soil constituents forming undissolved inorganic phosphates, or be resynthesized into organic compounds by soil micro-organisms. Such a concept provides a rational explanation of the results reported in this paper.

SUMMARY

Surface application of superphosphate to Quebec permanent pastures on brown forest soil results in an increase in the amount of readily soluble phosphate in the surface one-half inch layer of soil. In the years following fertilization this readily soluble phosphate gradually diminishes, so that three or four years after treatment the values approach that of the unfertilized soil. On the basis of our interpretation of the pot culture results, the readily soluble phosphate is to be considered available while it is in the process of decreasing. The soluble phosphate of untreated soil appears to be an equilibrium quantity, probably not varying significantly from year to year, and approached in the treated soil after the effectiveness of the application has worn off. The increase of wild white clover in the sward, and the yield increase over untreated pasture, are seen to be closely related to the amount of soluble phosphate produced by fertilization and remaining in the soil at the time of measurement.

The pot culture experiment has shown that the phosphorus uptake by pasture plants growing on this soil is not to be wholly attributed to the utilization of readily soluble phosphate. The phosphorus obtained by the plants was in all cases considerably more than could be attributed to decreases in the amount of readily soluble phosphate in the soil. The readily soluble phosphate may decrease, remain constant, or increase while the plants are withdrawing phosphorus. It is suggested that a considerable proportion of the phosphorus obtained by the plants came from the nucleotides known to exist in this soil. Decomposition of nucleotides would result in the release of phosphoric acid into the soil, thus providing a notable source of phosphorus for plant nutrition and the replenishing of inorganic phosphates in the soil.

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PRUNING STAKED TOMATOES

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Tomato growing is mainly divided into three particular phases of production: field tomatoes for the cannery crop, from which the first ripe fruit is to a large extent shipped to the fresh fruit market; staked tomatoes for table use; and greenhouse tomatoes used entirely for the fresh fruit market. This report deals with staked tomatoes grown in the open, and describes various methods of pruning which have been tried in order to produce as early a crop as possible. Over a period of years there have been tested essentially four different methods, and within each group the main consideration has been the amount of pruning and the type of pruning in relation to the time at which the operation was performed. The factor of time, so far as literature reviewed by the writer is concerned, has not been considered previously.

LITERATURE REVIEW

Pruning tomatoes has formed the basis of numerous experiments with varying procedure. Thompson (1), using the Bonny Best variety, compared plants staked and pruned to a single stem to unpruned plants, and obtained a lower yield per plant when pruned, but increased earliness. When the number of pruned plants was more than double the number of unpruned ones the plot yield was greater for pruning. In reviewing the literature he reports seven workers covering the period 1892–1933 reporting a higher yield on unpruned than on pruned plants. Edmond (2), using the Marglobe variety, in Mississippi for one year found no appreciable difference between pruned and unpruned plots. Stucky in Georgia and Whipple and Schermerhorn in Montana report results in which the pruned plants produced a larger yield per plant than unpruned ones. In Montana the yield of ripe fruit was greater on pruned plants. The total yield of green and ripe fruit was, however, greatest on unpruned plants. These results indicate earliness from pruning and a short season which prevents much of the later maturing fruit from ripening. The evidence submitted by Thompson indicates generally that pruning under many conditions induces early ripening. There are, however, notable exceptions from some sections where pruning has reduced earliness. Magruder (3), using the Bonny Best variety, in comparing unpruned plants to those pruned to 1, 2 and 3 stems and staked, found that pruning increased earliness during the first four weeks of harvesting and that differences between amount of pruning were not large enough to warrant any but the least expensive treatment, one stem, being used. Watts (4), working at Fayetteville and Hope, Arkansas, used in successive years at Fayetteville the Norton, Marglobe and Break O'Day varieties, and at Hope the Gulf State Market variety. There were sixteen treatments with various degrees of training in these experiments. He divided the picking season into three periods, early, midseason and late; and between years, stations, and treatments

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obtained somewhat variable results, concluding that pruning reduced early and total yields at Fayetteville and that no significant differences showed at Hope. Training plants to stakes irrespective of the method of pruning increased earliness and yield at Fayetteville, but resulted in no differences at Hope. He further mentions that the different varieties used at the two stations may in part account for the lack of agreement of results. Olney (5), after three years' trial, concluded that some varieties, more than others, are influenced by pruning. Walker (6), working at Indian Head, Saskatchewan, used the Bonny Best and Alacrity varieties. He grew plants pruned to a single stem, stopped these at 1, 2 or 3 trusses, and compared results to plants which were not stopped. He concluded that severe pruning induced earliness but decreased yield.

METHODS AND MATERIALS

Experiment I

In this experiment there were 4 treatments; plants were stopped at 2 and 3 trusses, and unchecked plants trained to one and two stems. There was variation in size and number of plots throughout the years of this experiment. In 1927 and 1928 each treatment was systematically repeated twice in 30-foot rows with 10 plants to a row. In 1929, 1930 and 1931 each treatment was replicated 3 times on the above basis, using the same size of plot, and in 1932 and 1933 each treatment was replicated 4 times in 15-foot rows with 5 plants to a row.

Experiment II

There were 4 treatments in this group. Plants were stopped at 4, 6, 8 and 10 trusses when the respective numbers had formed, and no further terminal growth was allowed to develop. Four- and 6-truss plants were trained to a single stem, 8- and 10-truss plants were trained to 2 stems, except in 1932, when 3 stems were allowed to develop. This number, however, was found to be too many for staked plants. Each year there were 4 replicated plots in 15-foot rows with 5 plants for each treatment. During the first three years the plots were systematically distributed; in the last 2 years they were arranged at random in the form of a latin square.

Experiment III

There were four treatments in this group essentially the same as in II, but instead of stopping the plants when the respective number of trusses had formed all were allowed to develop 10 trusses on 2 stems and they were then stopped at tens and headed back to fours, sixes and eights. Plot size and arrangement was as in II.

Experiment IV

In this group, time of pruning was the essential feature. Plants were trained to a single stem and stopped at weekly intervals on 4 different dates. In 1931, eight trusses were allowed to develop before the first stopping was done. With this number of trusses it was found that the pruning was delayed until too late, so in subsequent years the first pruning was done when the sixth truss had formed. There were 4 dates of stopping

at weekly intervals. Plot size and arrangement was on the same basis as outlined for II and III.

The variety used throughout the experiment was the Bonny Best, except in 1936, when the seed package was wrongly named. The variety that year was a large, coarse, pink-colored one. The rows and distance between plants each year gave a spacing of 36 inches on the square. Experiments II, III, and IV were mainly an outcome of I in order to study the effect of time of pruning in relation to yield and maturity. The experiments were carried out from 1927 to 1936 inclusive. There were no results in 1934, due to the crop being destroyed by blight.

RESULTS

In order to save space, yearly tables are omitted and only a final summary is given for each experiment. The crop yields given, unless otherwise stated, are for totals of marketable fruit at weekly intervals.

Experiment I. Plants Trained to 2 and 3 Trusses and 1 and 2 Stems

TABLE 1.—TOTAL YIELD AT WEEKLY INTERVALS FOR SEVEN CROP YEARS

Plants trained to	Period 1		Period 2		Period 3		Period 4		Period 5		Period 6		Total for season	
	lb.	oz.	lb.	oz.	lb.	oz.	lb.	oz.	lb.	oz.	lb.	oz.	lb.	oz.
2 trusses	50	8	142	11	238	7	319	11	358	12	378	13	400	2
3 trusses	50	2	137	11	260	9	428	0	564	10	657	0	714	8
1 stem	45	12	137	3	285	1	450	5	663	12	985	3	1260	5
2 stems	34	4	100	15	239	0	448	2	721	14	1168	2	1757	14

Table 1 summarizes very closely the trends which were obtained from year to year. The only noteworthy exception was in 1929, when at the second period 2-stem plants gave the highest yield and maintained that position throughout the balance of the season. As indicated above, severe pruning to 2 and 3 trusses induces early ripening during the first 10 to 14 days of the season. Following this period the returns fall off, due to light yield, and from the third to fourth interval plants trained to one stem come into the lead and maintain this position up to the fifth or sixth interval, at which time 2-stem plants gave the highest yield and maintained this superiority for the balance of the season. In other words, pruning to two and three trusses gave the largest amount of ripe fruit during the first 2 weeks of ripening, single stem plants led during the third and fourth week, and two-stem plants produced more than any of the above after the fifth week of ripening.

Under the climatic conditions where this experiment was conducted a comparatively small but quite variable percentage of fruit matures during the first 2 weeks of ripening. This condition is markedly influenced by temperature when the first blossoms open which to a large extent regulates the number of blossoms which set fruit. Also directly bearing on the percentage of the total crop during the first 2 weeks is the length of the picking season, which is largely influenced by rain in September and disease. When there is a high precipitation much of the September crop

is lost by cracking and disease. While there is ordinarily a premium for early ripe fruit there must as well be a satisfactory yield, and for practical purposes single stem plants which average from 6 to 8 trusses best meet this requirement. Throughout this and the other experiments referred to hereafter it was quite frequently noticed that one or two ripe fruits may occur on any treatment well in advance of others irrespective of treatment. Such fruits are considered to be from fortuitous setting rather than due to treatment.

Experiment II. Plants Stopped at 4, 6, 8 and 10 Trusses

In view of the fact that pruning in experiment I produced an effect on maturity, it was felt that the time of pruning in relation to the method might further modify results. With this in mind experiments II, III and IV were initiated. Experiments II and III received identical pruning. The time factor was the only variable apart from the four treatments, number of trusses in each group. A summarized table of results of plants stopped at 4, 6, 8 and 10 trusses is given below.

TABLE 2.—TOTAL YIELD OF RIPE FRUIT AT WEEKLY INTERVALS, 5 CROP YEARS

Plants trained to	Period 1		Period 2		Period 3		Period 4		Period 5		Period 6	
	lb.	oz.	lb.	oz.	lb.	oz.	lb.	oz.	lb.	oz.	lb.	oz.
4 trusses	44	7	136	6	227	9	312	0	404	6	495	12
6 trusses	35	4	132	3	247	1	344	3	486	10	658	14
8 trusses	34	11	130	0	242	5	377	10	518	9	770	8
10 trusses	37	14	129	0	234	8	339	3	480	4	797	11

The above table very closely approximates the results obtained in tabular form for each year with the exception of 1936, when a different variety was used. In 1936 ten-truss plants gave the highest yield throughout the season, which indicates the possibility of varying response to pruning with certain varieties. In 1932 blight destroyed a large percentage of the later crop with the result that 10-truss plants gave the lowest yield. The trend of results here is the same as shown in Table 1, maturity being hastened by pruning. In order to compare the effect of time of pruning reference must be made to Experiment III.

Experiment III. Plants Pruned Back to 4, 6, 8 and 10 Trusses after 10 Had Formed

The results for amount of pruning in this test were the same as those previously referred to, namely, the more severe pruning giving the largest amount of ripe fruit in the early part of the season. In both this and the previous experiment best results, considering earliness and yield, were from plants trained to 6 or 8 trusses. This is the average number of fruiting trusses which bear fruit in plants pruned to a single stem when they are allowed to develop their maximum height. The actual number of fruiting trusses depends on the setting of fruit on those first formed, and on disease

and climatic conditions at the end of the season. In order to compare the total yield of plants in experiments II and III Tables 3 and 4 are presented.

TABLE 3.—TOTAL AND YEARLY YIELD OF PLANTS STOPPED AT 4, 6, 8 AND 10 TRUSSES

—	4 trusses		6 trusses		8 trusses		10 trusses	
	lb.	oz.	lb.	oz.	lb.	oz.	lb.	oz.
1931	102	3	160	11	194	1	226	3
1932	105	4	152	13	185	6	182	10*
1933	88	12	82	1	96	10	81	0*
1935	57	10	93	7	108	13	109	10
1936	141	15	169	14	185	10	198	4
Total	495	12	658	14	770	8	797	11

* Low yields are due to blight infection during the latter part of the cropping season.

TABLE 4.—TOTAL AND YEARLY YIELD OF PLANTS PRUNED BACK TO 4, 6, 8 AND 10 TRUSSES

—	4 trusses		6 trusses		8 trusses		10 trusses	
	lb.	oz.	lb.	oz.	lb.	oz.	lb.	oz.
1931	110	7	160	5	204	6	227	12
1932	110	3	162	6	169	12	165	8
1933	101	3	113	8	113	5	91	1
1935	72	6	112	4	123	9	118	9
1936	147	8	210	1	243	3	232	2
Total	541	11	758	8	854	3	835	0

Tables 3 and 4, with two exceptions in 1932, indicate a heavier yield of fruit from plants which are allowed to develop up to 10 trusses and are then headed back than from plants stopped when a lesser number of trusses have formed. The most probable explanation for this performance is the increase in size of fruit due to increased leaf area, as referred to by Gustafson and Stoldt (7) who found a direct correlation between size of fruit and leaf area.

Experiment IV. Pruning at Weekly Intervals

In this experiment plants were trained to a single stem and divided into 4 groups, and groups were stopped or pruned back at weekly intervals. The first stopping was done when the sixth truss had formed. This is at approximately the time when the first fruits are in a semi-ripe condition. Results for 5 crop years gave no difference in earliness from any one date treatment. There were, however, as indicated in Table 5, differences in yield.

TABLE 5.—TOTAL AND YEARLY YIELDS, PRUNING TO 6 TRUSSES AT WEEKLY INTERVALS

—	1st pruning		2nd pruning		3rd pruning		4th pruning	
	lb.	oz.	lb.	oz.	lb.	oz.	lb.	oz.
1931	219	8	234	11	196	15	212	11
1932	135	0	135	0	145	12	153	1
1933	111	4	112	10	107	9	116	10
1935	111	10	120	2	99	3	133	1
1936	159	8	154	15	148	0	176	10
Total	736	14	757	6	697	7	792	1

The summary in Table 5 closely approximates individual plot yields from the yearly data. With the exception of 1931 the fourth pruning each year gave the highest yield and is further substantiation of the results in experiment III that delayed pruning has definite advantages in increasing yields. The third pruning is an exception to the above for which no satisfactory explanation can be offered.

DISCUSSION AND CONCLUSIONS

Tomato plants of the Bonny Best variety are definitely affected by pruning. In 1936 when a different variety was used there was some evidence that there may be a definite varietal response to pruning practices, as is referred to by Olney (5). With plants pruned to 4 or fewer trusses there has been earlie rmaturing fruit than with those having a greater fruiting area. Maturity is hastened and yield decreased in proportion to the amount of pruning, which results are in accordance with those of Walker (6). These results are not in agreement with those obtained by all other workers some of whom report no increased earliness due to pruning. An important factor not always enumerated in these other experiments is the length of periods into which the season is divided. In the work reported in this paper, had the season been divided into comparatively long periods of 3 to 4 weeks duration, earliness for severe pruning would not have manifested itself, and results at four to five weeks would have been discordant between plants trained to one and two stems. There has also been with severe pruning, 2 and 3 trusses, a marked tendency for the fruits to become affected by sunscald. Irrespective of treatment, individual ripe fruits will mature as early on any one treatment as another, even though a given treatment will on the whole produce a generally earlier crop. Thompson (1) working in New York obtained similar results. Where plants are pruned back to 4 or 6 trusses best results are obtained when growth is allowed to develop on 2 stems and when 10 trusses have formed head back to the required number. This practice does not increase earliness but it does increase the yield. Thompson (1) reports size of fruit increased by pruning. Watts (4) found no difference in average size of fruit from any system of pruning or training. Walker (6) obtained increased size of fruit from severe pruning, while Gustafson and Stoldt (7), working under greenhouse conditions, definitely correlated size of fruit increasing with the amount of foliage. An additional advantage from delayed thinning is a saving in labour, as there is no need to go over the plants at frequent intervals to cut out small shoots. The bulk of the work can be done in fewer operations. Thompson (1) on the other hand reports that unless the shoots are pruned out while small much of the advantage will be lost. Experiments III and IV in this paper show increased yield for delayed pruning. The plants, though, were definitely pruned to either one or two stems within a month after the date of transplanting to the open. Unless there is a high premium for the first fruit, yield cannot be unduly sacrificed, and further when there is not an adequate market at a remunerative price for the late maturing crop the practice of growing for highest yields is equally unsatisfactory. The results of these experiments have shown that the middle course is the best. This consists of pruning plants to a single stem and allowing them to develop to their maximum height. Normally such plants will bear

fruit on 6 to 8 trusses. Data from unpublished experiments have shown that the maximum yield from a given area for plants so trained is when they are spaced at 12 inches in rows 3 feet apart.

SUMMARY

Evidence has been presented to show that fruiting habits of tomato plants are influenced by pruning. The methods involved have included the amount of pruning and the time at which the work is done, and have chiefly indicated the following:

1. Maturity is hastened by the most severe pruning practices.

2. Commensurate with yields and sunscald injury too severe pruning can be done.

3. Delayed pruning gives increased yields.

4. Unchecked plants trained to a single stem have given the most satisfactory results, considering earliness and total yield.

5. The evidence, while fragmentary, indicates the possibility of varietal differences in response to pruning.

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DOWNY MILDEW OF THE ROSE IN BRITISH COLUMBIA[1]

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In July, 1937, downy mildew of the rose, *Peronospora sparsa* Berk. was observed in a garden in West Vancouver, British Columbia, where it did considerable damage to the varieties Portadown and Lord Lonsdale. Slight infection was also observed on the varieties Mrs. Gladys Peach, Mrs. H. Morse, Mrs. Laxton, Lal, Crimson Glory, Trigo, and Mrs. C. Lamplough. The garden referred to is situated in a low area, where air drainage is poor and the humidity high. The location provided an ideal environment for the development of the disease under outdoor conditions. Slight symptoms have since been observed on plants grown outdoors in two other localities, indicating that it may be widely distributed.

The disease has been previously reported from Europe and America, but appears to be mostly confined to greenhouses. Eriksson (1) in referring to infection in greenhouses states that "in 1884 a grower in Denmark lost more than two thousand rose trees."

Symptoms of the disease were found on the leaves, stems, and flowers. Affected leaves showed pale red to purplish red, irregular spots and areas on the laminas and frequently along the veins. These diseased areas differed from those of black spot caused by *Diplocarpon Rosae* (Lib.) Wolf. in being lighter in colour, less defined and not fibrillose along the margins (Figure 1). Infection symptoms on the stems appeared as reddish to purplish areas, and on the flowers as brown spots or areas on the petals. Most of the diseased flowers were spoiled, particularly when infection had occurred in the early bloom stage.

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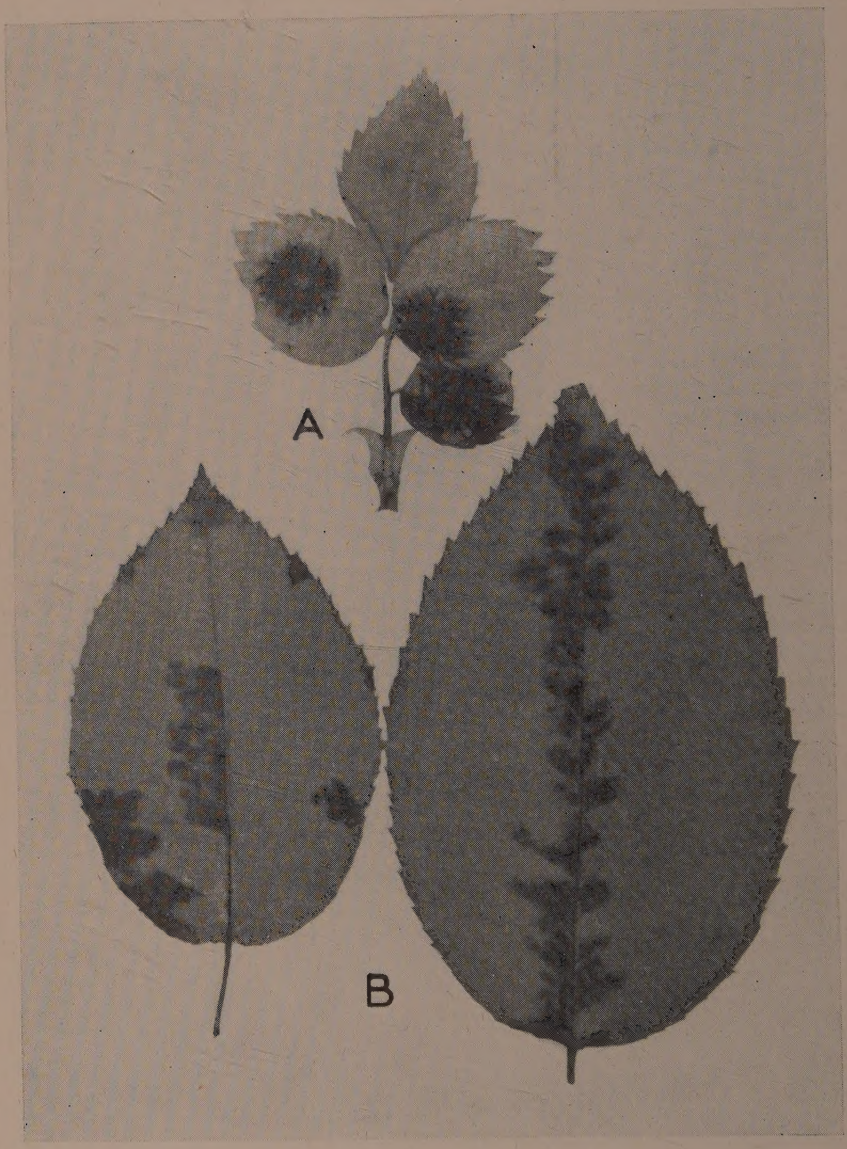

FIGURE 1. A. Symptoms of Black Spot, *Diplocarpon Rosae* on rose leaf. B. Symptoms of Downy Mildew, *Peronospora sparsa* on rose leaves.